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#222 NOVEMBER 2023

Sky at Night

THE UK'S BEST-SELLING ASTRONOMY MAGAZINE

AFTER THE ISS

In orbit for 25 years, the Space Station is nearer its end than its beginning. What comes next?

DANCE OF THE MOONS
See stunning transits & eclipses on Jupiter

HOW WE'LL FIND SIGNS OF LIFE ON ALIEN WORLDS

SOLVING THE MYSTERY OF JUPITER'S SHIFTING STRIPES

EXPLORE THE DEEPEST EVER VIEW OF THE ORION NEBULA

6 WAYS TO PREDICT AN AURORA DISPLAY

STARLESS GALAXY FIND EXCITES ASTRONOMERS

Welcome

We're on the cusp of an exciting new era of space stations

Twenty-five years ago this month, the first module of the International Space Station was launched. From this small seed, the ISS has grown to be larger than a football field and a lasting beacon of international cooperation. But with the space station reaching the end of its serviceable lifetime, the ISS era is coming to an end. On **page 36**, Sean Blair looks at what will come next to continue humanity's presence in space.

A quarter of a century is just two years on Jupiter, which really puts its distance from us (615 million kilometres) in perspective. Even so, in November the Solar System's biggest planet will be hard to miss! It's at opposition this month and at its biggest, brightest and highest in the night sky for the year. It's a stunning object to observe even in modest detail and, as a bonus, you can also catch some fascinating interactions between it and its largest moons. Pete Lawrence has all the details in the Sky Guide from **page 43**.

The other most prominent detail that a telescope will reveal on Jupiter is its distinctive striped atmosphere. These belts and zones change over short timespans (astronomically speaking) and it will be fascinating to watch for these changes, particularly in the light of Giles Sparrow's feature on **page 60**. Here he investigates how astronomers are today able to peer deeper into the planet's strange interior to reveal what is driving the continual shifts in the cloud tops that make up its visible surface.

Enjoy the issue!

Chris Bramley, Editor

PS Our next issue goes on sale on Thursday 16 November.

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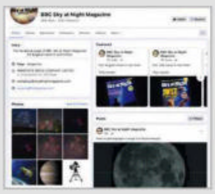
Sky at Night – lots of ways to enjoy the night sky...

Television
Find out what *The Sky at Night* team have been exploring in recent and past episodes on page 18

Online
Visit our website for competitions, astrophoto galleries, observing guides and more



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Follow us on Twitter, Facebook and Instagram for space news, astro images and website updates

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Discover the best things to see in the night sky every week by listening to our Star Diary podcast

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eNewsletter
The best targets to observe each week, delivered to your inbox. Visit **bit.ly/skynewsletter**

Find out more at: www.skyatnightmagazine.com

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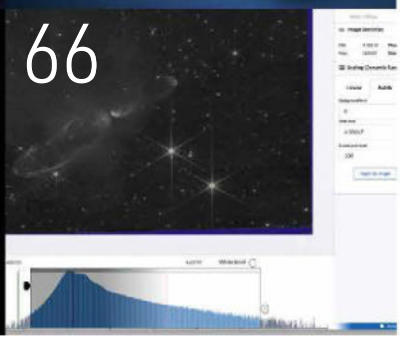
16-PAGE CENTRE PULLOUT

New to astronomy?

To get started, check out our guides and glossary at **www.skyatnightmagazine.com/astronomy-for-beginners**



This month's contributors

Sean Blair

Science writer

"The Space Station has been operating for 25 years, but won't last forever. However, numerous new space stations are planned, expanding humanity's presence in space." **Sean reveals what comes next on page 36**

Joe DePasquale

Image processor

"Did you know that images from the world's most advanced space-based observatory are processed using the same techniques many ground-based astrophotographers use?" **Discover the similarities on page 66**

Jane Green

Astronomy author

"The electro-magnetic spectrum is the fundamental tool astronomers use to explore the Universe, and there's so much more than what we can see with our eyes." **Find out what the spectrum can show us on page 72**

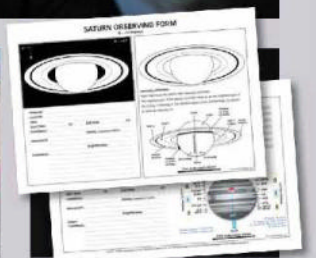
Extra content ONLINE

Visit **www.skyatnightmagazine.com/bonus-content/pms952m** to access this month's selection of exclusive Bonus Content

NOVEMBER HIGHLIGHTS

Interview: Intelligent life beyond Earth?

Astronomer Adam Frank on the search for alien life, what it would mean and what he really thinks about UFOs.



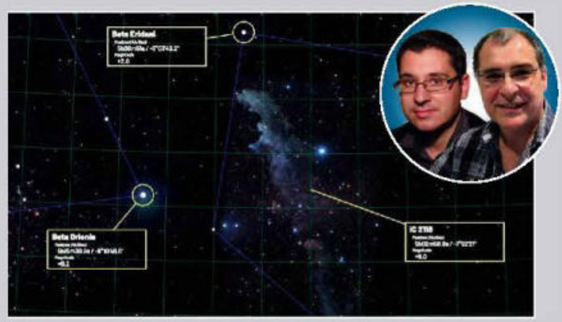
Sky at Night meets the Very Large Telescope

Maggie travels to Chile's Atacama Desert to explore one of the most advanced observatories in the world.

Download our planet observing forms

Download and print out our observing forms to record your observations of the Sun and planets throughout the year.

The Virtual Planetarium



Pete Lawrence and Paul Abel guide us through the best sights to see in the night sky this month.

EYE ON THE SKY

LIFE ON THE EDGE

Milky Way outlier Terzan 12 is a glittering star field in this new Hubble image

HUBBLE SPACE TELESCOPE, 7 SEPTEMBER 2023

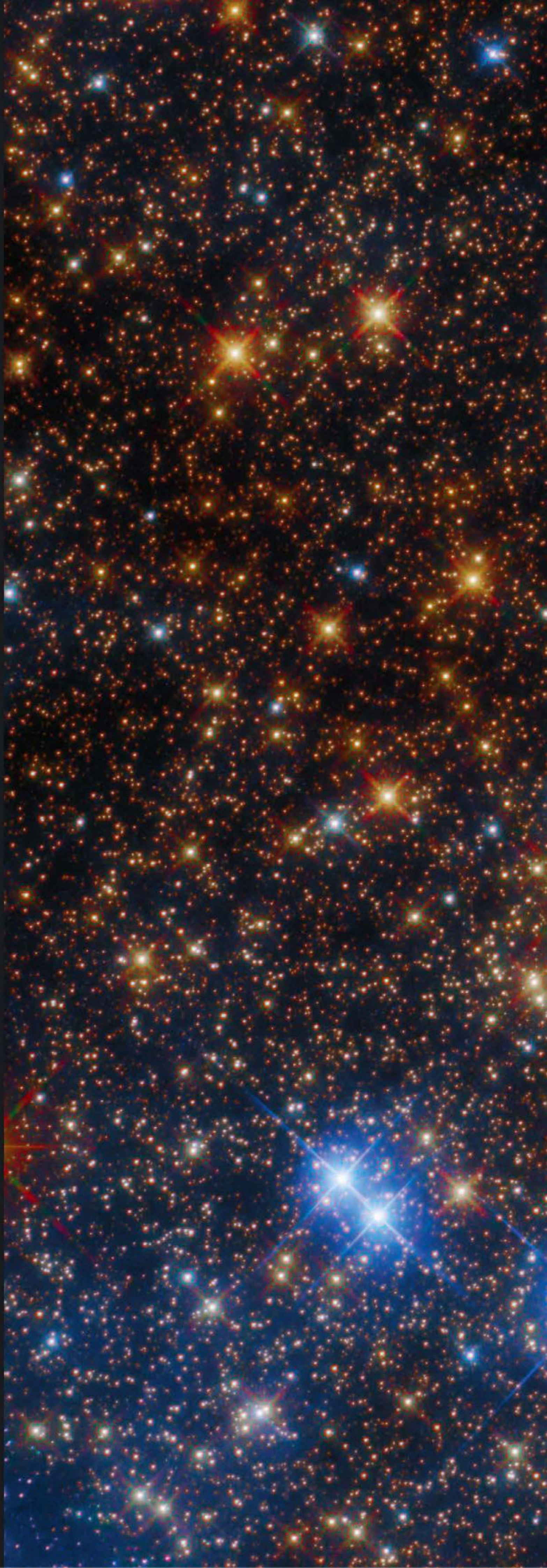
Lying some 15,000 lightyears from Earth in the constellation of Sagittarius, the globular star cluster Terzan 12 is one of the Milky Way's more peripheral members. Unlike their open cluster cousins – which are found between the Galaxy's spiral arms – the Milky Way's 150 globular clusters, made up of very ancient stars, orbit the Galactic centre far above and below the Galactic plane, like bees swarming around a hive.

Confusingly, Terzan 12 was the last of 11 such clusters to be discovered by Turkish-Armenian astronomer Agop Terzan in the 1960s and 70s, its name deriving from the fact that the previously identified Terzan 5 and Terzan 11 turned out to be the same object. It's also worth noting that the larger, brighter blue and red stars in this picture are not part of Terzan 12 itself, but merely lie along the line of sight between cluster and telescope.

ESA/HUBBLE & NASA/R. COHEN (RUTGERS UNIVERSITY)

MORE **ONLINE**

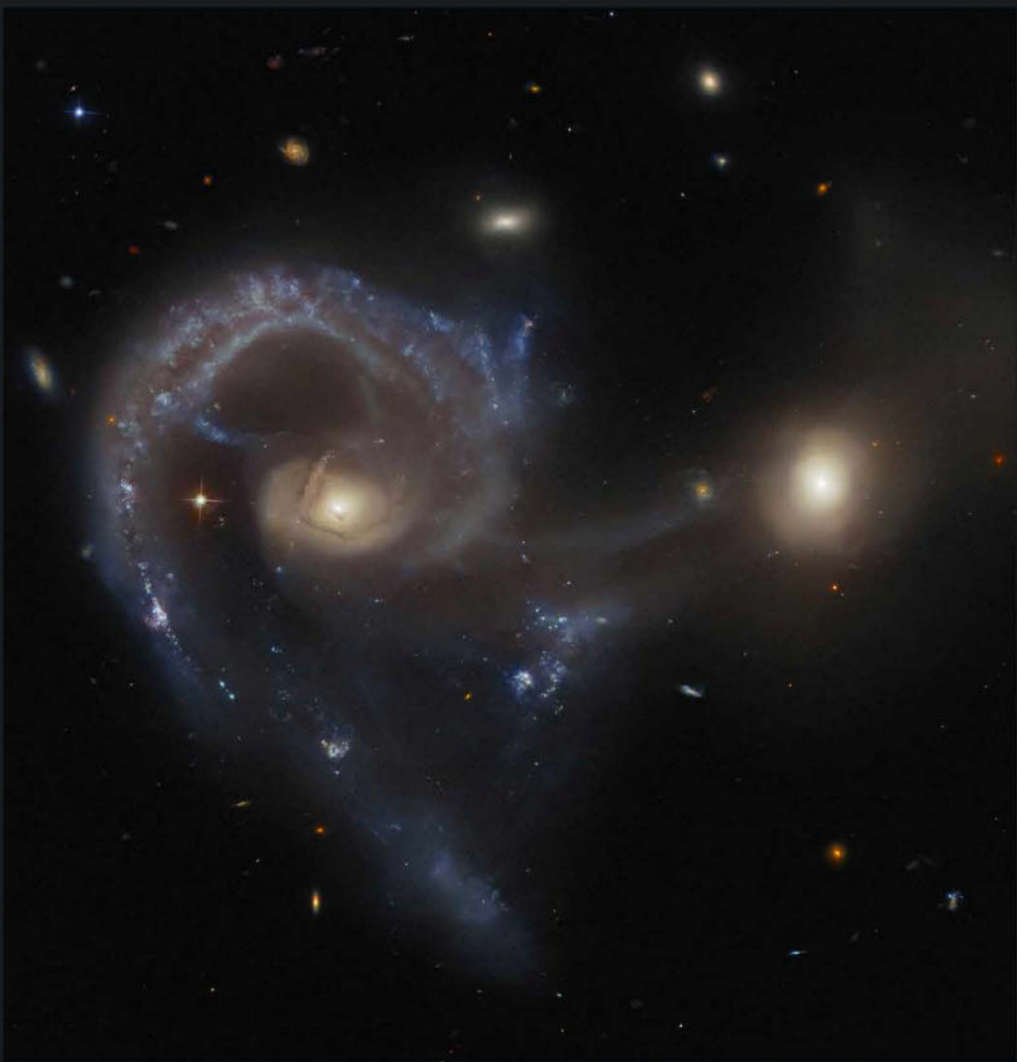
Explore a gallery of these and more stunning space images



△ Martian riverbed

MARS RECONNAISSANCE ORBITER, 18 AUGUST 2023

This shows, in spectacular close-up detail, an impact crater in Mars's northern Arabia Terra region. But it's not the crater that's of interest: rather it's the two vertical lines just to its left which mark the edges of what was once a riverbed. Like many such former water channels on Mars, it has filled in with sediment over the millennia, but the water's previous course remains clearly visible.



The Seyfert diet ▷

HUBBLE SPACE TELESCOPE, 18 SEPTEMBER 2023

This unusual object is Arp 107, comprising two galaxies that are in the process of colliding and merging. The larger one on the left is a Seyfert galaxy – an active galaxy with a very bright, quasar-like nucleus – and will eventually consume its smaller companion on the right. Look closely and you can see a 'bridge' of gas and dust between the two, formed as matter is gradually transferred.

NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA, ESA/HUBBLE & NASA/J. DALCANTON, NASA/JPL-CALTECH/SWRI/MSSS, ESA/WEBB/NASA/CSA/TOM RAY (DUBLIN)

△ Io in the sky

JUNO, 30 JULY 2023

We're all used to seeing Jupiter's third-largest moon as a small circle transiting its surface, but this stunning new image captures close-up views of both planet and satellite in a single frame. It was taken by NASA's Juno probe as it made its 53rd close fly-by of Jupiter, with the raw data then processed by citizen scientist Alain Mirón Velázquez.

Let it flow ▷

JAMES WEBB SPACE TELESCOPE, 14 SEPTEMBER 2023

This startling image shows Herbig-Haro 211, where jets of gas emitted by a newly formed star collide with the surrounding cloud of gas and dust at speeds of up to 100km/s. As they collide, molecules of hydrogen, carbon monoxide and silicon monoxide emit different frequencies of infrared light, enabling scientists to map out the structure of the outflows.

The latest astronomy and space news, written by Ezzy Pearson

BULLETIN

▲ The recovery team, including Dante Lauretta (right), with the capsule at the landing site in the Utah desert

NASA/KEEGAN BARBER

OSIRIS-REx returns asteroid sample to Earth

The asteroid's rock dust will reveal what our early Solar System was like

After an eight-year journey of almost four billion kilometres, NASA's OSIRIS-REx spacecraft has finally delivered a precious sample of space dust it collected from asteroid Bennu. The pristine space rocks will help planetary geologists examine what our Solar System looked like as the planets were forming.

OSIRIS-REx has spent almost two years studying the asteroid Bennu. On 20 October 2020, the craft collected an estimated 250g of material from the surface, stowing it inside a sample-return capsule.

On the morning of 24 September 2023, OSIRIS-REx released this capsule when it was 102,000km away from Earth. After entering the atmosphere at 44,500km/h, the capsule was safely slowed down by aerobraking and parachutes, before landing just outside Salt Lake City, Utah at 14:52 UT.

It was found by NASA's recovery team about 15 minutes later and wrapped up for transportation to a temporary clean room. Here, the capsule was purged with non-reactive nitrogen to prevent contamination and then was transported to the Johnson Space Center in Houston and carefully opened in a specially built facility, so the sample could be extracted, weighed and catalogued.

"Successfully delivering samples from Bennu to Earth is a triumph of collaborative ingenuity and a testament to what we can accomplish when we unite with a common purpose," says Dante Lauretta, principal investigator for OSIRIS-REx at the University of Arizona.

The samples are now being sent to scientific institutions around the world for analysis. Bennu formed when the Solar System was 10 million years old. Critically, the rocks could reveal how organic molecules, the raw ingredients of life on Earth, came to exist on our planet's surface.

"We now have the unprecedented opportunity to analyse these samples and delve deeper into the secrets of our Solar System," says Lauretta.
asteroidmission.org

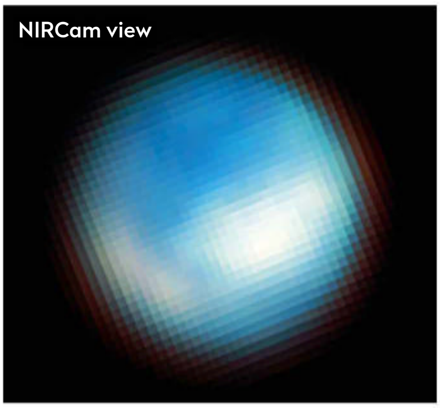
Comment
by Chris Lintott

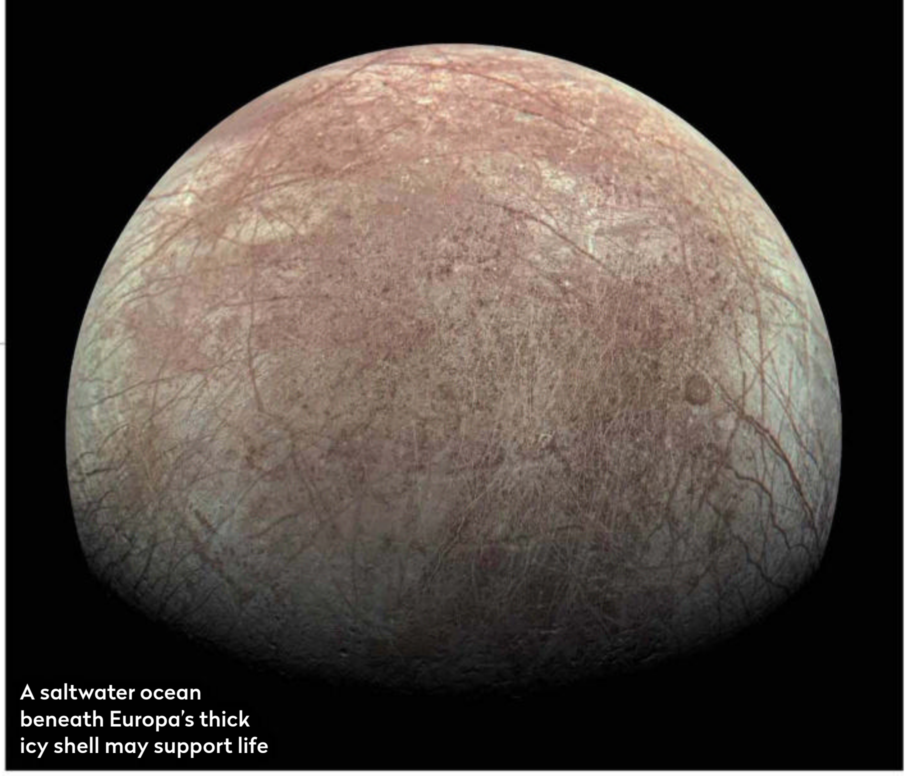
Celebrating along with the OSIRIS-REx team was a familiar face who played a critical role in the mission. Brian May, an expert in dust in the Solar System as well as a rock superstar, has a third passion to go with astronomy and music: 3D photography. May and colleagues created 3D versions of images captured by OSIRIS-REx initially for fun, but things got more serious once he sent them to Dante Lauretta.

May's team wound up creating around 50 3D views of potential landing sites, helping the spacecraft to gather its samples.

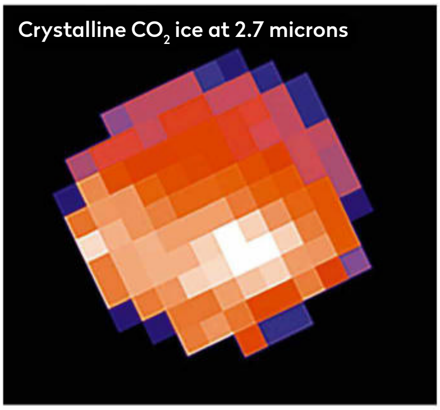
Hearing about their collaboration made me realise quite how difficult a task Lauretta's team have pulled off – with a little help from May and friends.

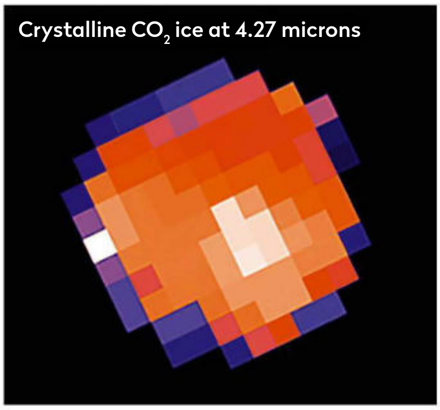
Chris Lintott co-presents *The Sky at Night*

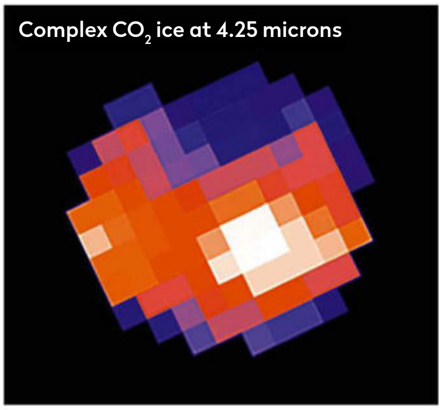




A saltwater ocean beneath Europa's thick icy shell may support life







▲ JWST identified carbon dioxide (white pixels) on the icy surface of Europa that likely originated in the moon's subsurface ocean

JWST traces carbon across worlds

The telescope's observations are tracking the building blocks of life across the Galaxy

When it comes to detecting carbon-based chemicals in the atmospheres of other planets, no telescope can match the James Webb Space Telescope (JWST). Carbon-based chemicals form the building blocks of life, and the JWST is helping to track their distribution both within our Solar System and beyond, as shown in two recent discoveries.

Beneath the icy crust of Jupiter's moon Europa lies a saltwater ocean, one of the few places in our Solar System that could potentially be habitable. The region of Europa called Tara Regio – a yellowish area of 'chaos terrain' – offers a unique way to glimpse the subsurface ocean, as its jumble of geological features appear to indicate the surface ice is interacting with the ocean below.

When JWST looked at Tara Regio, it found signs of carbon dioxide. As this gas is unstable and the terrain is geologically young, it must have been deposited relatively recently, and most probably came from the ocean rather than an external source.

"We now think that we have observational evidence that the carbon we see on Europa's surface came from the ocean," says Samantha Trumbo from Cornell University, who led one of two studies on the region. "That's not a trivial thing," she added. "Carbon is a biologically essential element."

The study came a few weeks after another team announced JWST had found not only carbon, but also a potential life signature in the atmosphere of an exoplanet. K2-18b is around 2.6 Earth radii, making it sub-Neptune size, and sits within the habitable zone of its red dwarf star, where liquid water can potentially pool on the surface.

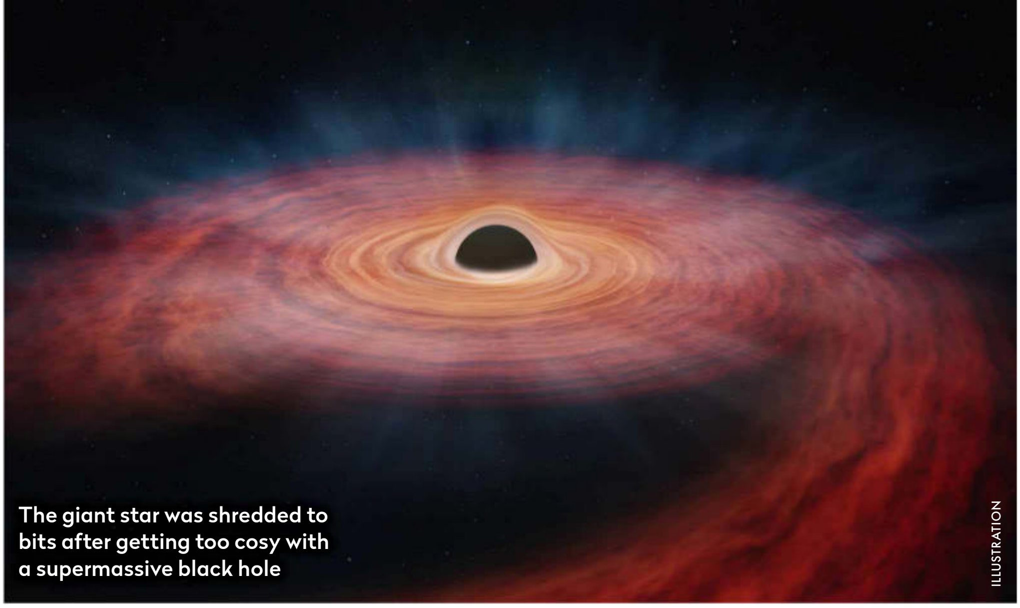
JWST detected clear signs of both carbon dioxide and methane on the planet, as well as a tantalising hint of dimethyl sulphide (DMS). On Earth, DMS is only produced by life and the bulk of it found in our atmosphere is created by tiny marine algae known as phytoplankton. The detection is currently very tenuous, though, and will require further validation.

"Upcoming [JWST] observations should be able to confirm if DMS is indeed present in the atmosphere of K2-18b at significant levels," says Nikku Madhusudhan from the University of Cambridge, who led the study.

Despite the uncertain nature of the find, Madhusudhan is hopeful of what the signal could mean. "Our ultimate goal is the identification of life on a habitable exoplanet, which would transform our understanding of our place in the Universe."

webbtelescope.org

GERONIMO VILLANUEVA (NASA/GSFC) ALYSSA PAGAN (STSCI), NASA/JPL-CALTECH/SWRI/MSSS/IMAGE PROCESSING: KEVIN M. GILL, NASA/CXC/M.WEISS, NASA'S SCIENTIFIC VISUALIZATION STUDIO, ISRO



The giant star was shredded to bits after getting too cosy with a supermassive black hole

Huge star spied being eaten by black hole

Star is one of the largest ever witnessed being destroyed this way

A star that was caught being devoured by a giant black hole in a nearby galaxy turned out to have been one of the largest stars seen being consumed in this way, a recent study has found.

The event, called ASASSN-14li, was spotted in a galaxy located 290 million lightyears away in 2014, but astronomers have been studying the aftermath ever since. It occurred when the star strayed too close to a black hole and was torn apart – what is known as a tidal disruption event. Much of the star's gas left over from the event remained in orbit, but a portion was blown away by strong winds created by the black hole's accretion disc.

To study this ejected gas, astronomers used X-ray observatories such as NASA's Chandra and ESA's XMM-Newton to observe the stellar debris. They were able to take spectra of the gas and learn what elements were contained within it.

They found the gas has an abundance of nitrogen, but a lack of carbon. The unique pattern of elements indicated a single star had been consumed but that the mass of this star was around three times that of the Sun. If this is the case, it would be perhaps the most massive star ever seen being torn apart like this.
Chandra.si.edu

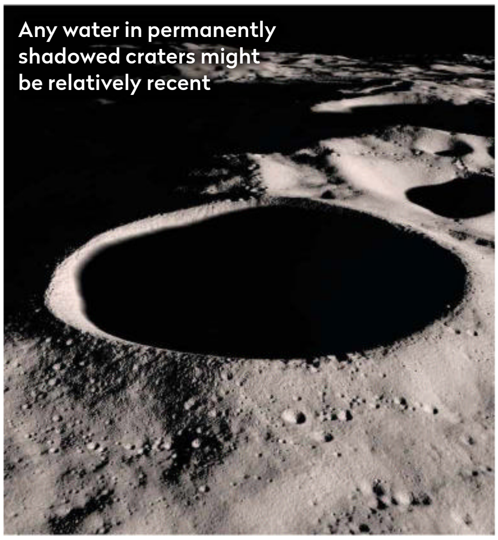
Moon's deep shadows are surprisingly young

The permanently shadowed areas of the Moon's polar regions could be much younger than previously thought, a new study suggests.

The deep craters at the lunar southern pole have come to attention in recent years after water ice was discovered hidden within their permanently shadowed corners. Initially, planetary scientists thought these craters were created around the time the Moon formed 4.5 billion years ago, meaning the water trapped there could provide a window back to the earliest times of the Solar System, when the planets were forming.

However, we know the distance between Earth and the Moon is slowly, but constantly, changing and this would affect the angle of the Moon's tilt. A team of researchers tracked the history of this tilt and found that the craters were only tipped into permanent shadow around 3.4 billion years ago. Any ancient water would have long disappeared by then, meaning any locked away in the craters comes from a later date.

"These findings change the prediction for where we would expect to find water ice on the Moon, and it dramatically changes estimates for how much water ice there is on the Moon," says Norbert Schörghofer from the Planetary Science Institute, which led the study.
psi.edu



Any water in permanently shadowed craters might be relatively recent

NEWS IN BRIEF

Indian lunar mission fails to wake

India's Chandrayaan-3 lunar mission successfully operated for two weeks (a lunar day) but has failed to wake from its hibernation through the lunar night. The spacecraft landed near the lunar south pole on 23 August. While operational, both lander and rover sent back many images and even found signs of sulphur, indicating potential past volcanic activity.

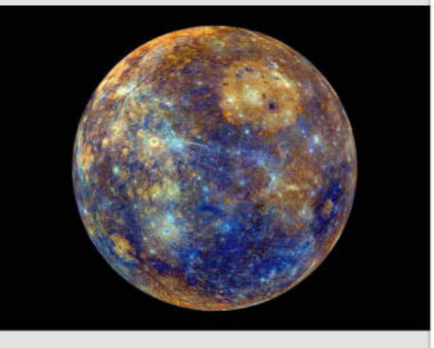
Comet's tail torn away

Comet Nishimura (C/2023 P1) had its tail ripped away after it was struck by a solar storm on 2 September while travelling towards the Sun. The tail grew back over the following few days, but with the Sun nearing its peak of activity it continued to buffet the comet throughout its approach.

Pulsar ebbs and flows

A dozen space- and ground-based telescopes recently joined forces to observe an unusual pulsar that appears to switch between two brightness modes. The observations revealed the shift arises from material getting closer and closer to the pulsar, only to clash against the wind coming from it.

NEWS IN BRIEF



Mapping Mercury's radiation

Solar radiation constantly bombards Mercury's surface, altering both the surface and atmosphere. For the first time, geologists have mapped the fall of these particles by geographical location rather than time of day, allowing them to investigate how specific features are affected.

First fine issued for space junk

The US government has issued its first-ever space junk fine. Telecoms company Dish Network was fined $150,000 for failing to dispose of one of its satellites, which was in geostationary orbit. The satellite was meant to move 300km into a 'graveyard orbit', but ran out of fuel after only 122km.

Curiosity keeps climbing

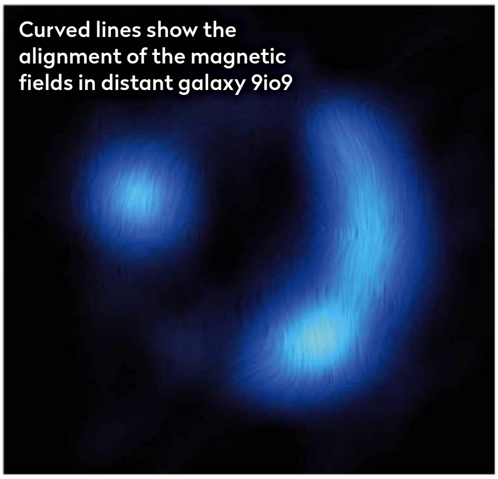
NASA's Curiosity rover has finally reached a ridge created by a giant flood three billion years ago. The flood swept boulders and mud down the slope of Mount Sharp, giving Curiosity a way to view the geology of regions higher up the mountain which it might not otherwise reach.

NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/CARNEGIE INSTITUTION OF WASHINGTON, ALMA (ESO/NAOJ/NRAO)/J. GEACH ET AL. ESO/P. IRWIN ET AL.

BULLETIN

Youngest-ever galactic magnetic field spotted

Galaxies developed fields when they were just 2.5 billion years old



Curved lines show the alignment of the magnetic fields in distant galaxy 9io9

Though you might not be able to feel it, there is a magnetic field running through our entire Galaxy. Now, astronomers have managed to detect the most distant example of a galactic magnetic field ever spotted.

"This discovery gives us new clues as to how galactic-scale magnetic fields are formed," says James Geach from the University of Hertfordshire, who led the study.

The field was observed in the galaxy 9io9, which was discovered with the help of the BBC's *Stargazing Live* viewers in 2014. The light from 9io9 has been travelling for 11 billion years, meaning we are viewing it as it was when the Universe was just 2.5 billion years old. Some of this light was emitted from dust grains that were aligned along the galaxy's magnetic field, meaning the light is polarised. Astronomers were able to measure this polarisation using the Atacama Millimeter/Submillimeter Array (ALMA) to find that even at such a cosmically young age, 9io9 already has a full magnetic field spanning around 16,000 lightyears, suggesting these magnetic fields form when the galaxies are still young.

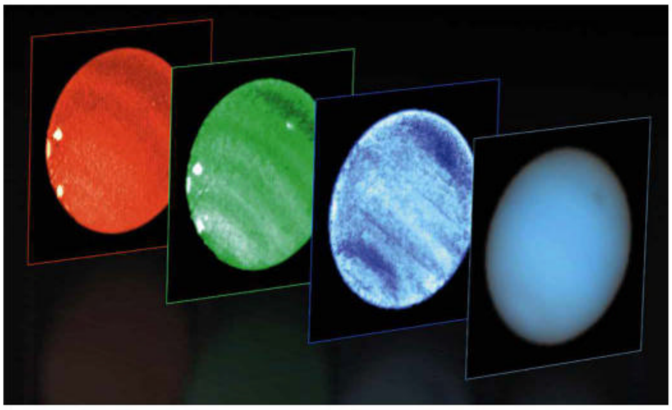
almaobservatory.org

Neptune 'spotted' from the ground

Over three decades after they were first discovered, astronomers have finally managed to observe the dark spots in Neptune's atmosphere from the ground.

Ever since they were first seen by Voyager 2 in 1989, the spots have mystified planetary scientists. They have since been monitored by space telescopes like Hubble. Unfortunately, they disappear and reappear every few years, making them difficult to study.

When a new spot was discovered in 2018, astronomers used the Very Large Telescope to not just see the spot but also take a spectrum of the light reflected from the planet. As different wavelengths of light pass through different layers of the atmosphere, the spectra allowed them to examine the spot in three dimensions. This revealed that the spot is in the hydrogen sulphide condensation layer beneath the top layers of methane, and that it was not alone.



▲ **Multiwavelength data revealed the large dark spot and a never-before-seen bright cloud**

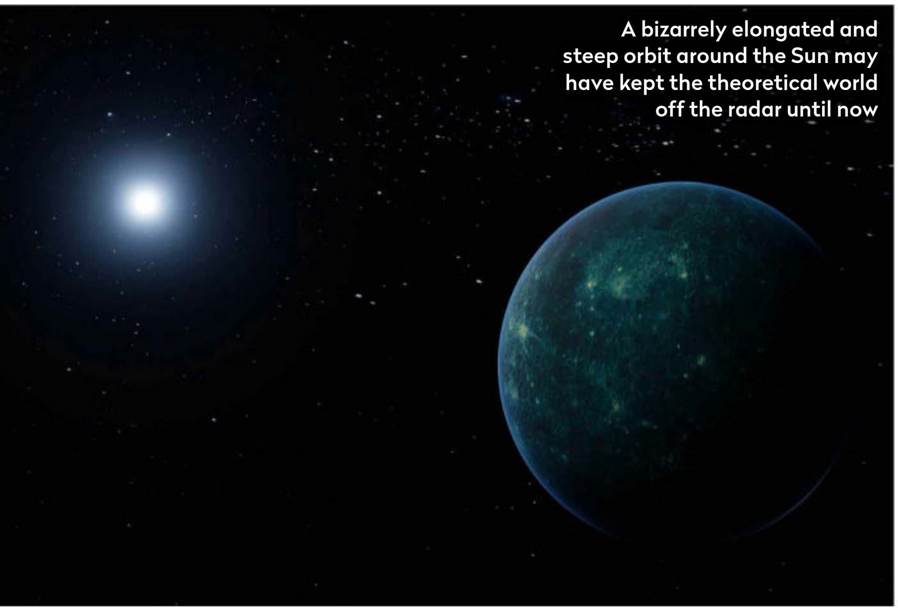
"In the process we discovered a rare, deep, bright cloud that had never been identified before, even from space," says Michael Wong from the University of California, Berkeley, who helped with the study.

This new cloud is beside the larger main dark spot and similar to 'companion' clouds seen at higher altitudes.

eso.org

Our experts examine the hottest new research

CUTTING EDGE



A bizarrely elongated and steep orbit around the Sun may have kept the theoretical world off the radar until now

Is another Earth-sized planet hiding in the Solar System?

A hypothetical Planet Nine in the distant Kuiper Belt could explain several observed oddities

The trans-Neptunian objects (TNOs) are icy bodies orbiting in the dark, outer recesses of the Solar System beyond the orbit of Neptune. In recent years, astronomers have noticed a number of oddities about the orbits of some TNOs, which cannot easily be explained by any single current model of Solar System development.

For example, there are a significant number of TNOs with high orbital inclinations, but they lie too far out to have been gravitationally nudged by Neptune. Theories such as the close pass of a rogue planet are also unable to properly explain their presence. Additionally, several 'extreme' TNOs have been discovered on exceptionally elliptical orbits at extreme distances from the Sun – such as the dwarf planet Sedna, which has a perihelion distance of 76 AU (where one AU is the distance between the Sun and Earth) and travels a staggering 937 AU out for its aphelion. It's difficult to explain how these worlds became perturbed into such elongated orbits.

One proposed explanation, although currently still pretty controversial, is that such mysteries with the TNOs could be due to the presence of a large, as-yet undiscovered planet in the Kuiper Belt, referred to by some as Planet Nine. Patryk Sofia Lykawka and Takashi Ito, at Kindai University and the National Astronomical Observatory of Japan, respectively, have been using computer models of the outer Solar System to study how such a hypothetical Kuiper Belt planet might affect the orbital structure of TNOs.

They found that a roughly Earth-sized planet, 1.5–3 times the mass of our planet, on an elliptical orbit with a perihelion of about 200 AU and inclined out of the plane of the Solar System by around 30°, could explain some of these weird properties of the outer Kuiper Belt. What's more, the presence of such a planet is also compatible with the observed populations of TNOs in orbits closer to the Sun.

It's important to note that this research falls far short of an actual detection of an Earth-mass planet in the far outer Solar System – there is no direct observational evidence for this. Instead, what Lykawka and Ito are saying is that the potential existence of such a planet is at least consistent with certain observed characteristics of the outer Solar System, and indeed may be the cause behind some of them. But most importantly for such extraordinary claims, the astronomers make specific predictions about other features that would be created by such a planet – namely, the existence of two populations of TNOs beyond 150 AU that have been perturbed by the Kuiper Belt planet's gravity. Crucially, these predictions can be tested by future observations and so provide the means by which the existence of such an Earth-sized planet could be either corroborated or refuted – a crucial part of science.

"Such a planet is at least consistent with certain observed characteristics of the outer Solar System"

If there is in fact such a planet hidden in the Kuiper Belt, it would not only represent an exciting discovery in itself, but, as Lykawka and Ito say, could also offer new insights into our understanding of how planets form and the orbital development of the Solar System beyond Jupiter.

Prof Lewis Dartnell is an astrobiologist at the University of Westminster

Lewis Dartnell was reading… *Is There an Earth-like Planet in the Distant Kuiper Belt?* by Patryk Sofia Lykawka and Takashi Ito
Read it online at: arxiv.org/abs/2308.13765

A starless galaxy?

A potentially all-dark-matter galaxy has put astronomers on Cloud-9

Prof Chris Lintott is an astrophysicist and co-presenter on *The Sky at Night*

A mysterious blob of gas found in the vicinity of the spiral galaxy M94 is exciting astronomers. It might be the first example of a type of object that has long been predicted by our leading cosmological theory: a small galaxy with gas, dark matter… and no stars.

Our understanding of how gravity sculpts structure in the Universe says that from the tiny initial fluctuations in density that we see in the cosmic microwave background, objects of all masses will form. But only in the largest – those with a mass above a critical limit, which changes over time – is gravity expected to be strong enough to reach the density required for star formation to happen.

As a result, scattered all over the Universe there should be smaller, failed systems that didn't reach this limit, which have been given the convoluted but more positive name of REionization-Limited-HI Clouds (RELHICs for short) by the authors of this month's paper, Alejandro Benítez-Llambay and Julio F Navarro. Has the first of these failed, starless galaxies been found?

Maybe. A team of Chinese astronomers using the new Five-hundred-meter Aperture Spherical Radio Telescope (FAST) in southwest China – think a larger and more modern version of the recently collapsed famous Arecibo dish in Puerto Rico – detected radio waves at a wavelength of 21cm. These are associated with hydrogen, coming from a point in the sky just slightly less than a degree from M94, in the constellation of Canes Venatici. If the emission is indeed from hydrogen, it seems to be receding from us at about the same speed as the more massive galaxy, making it very likely to be part of the same cosmic group.

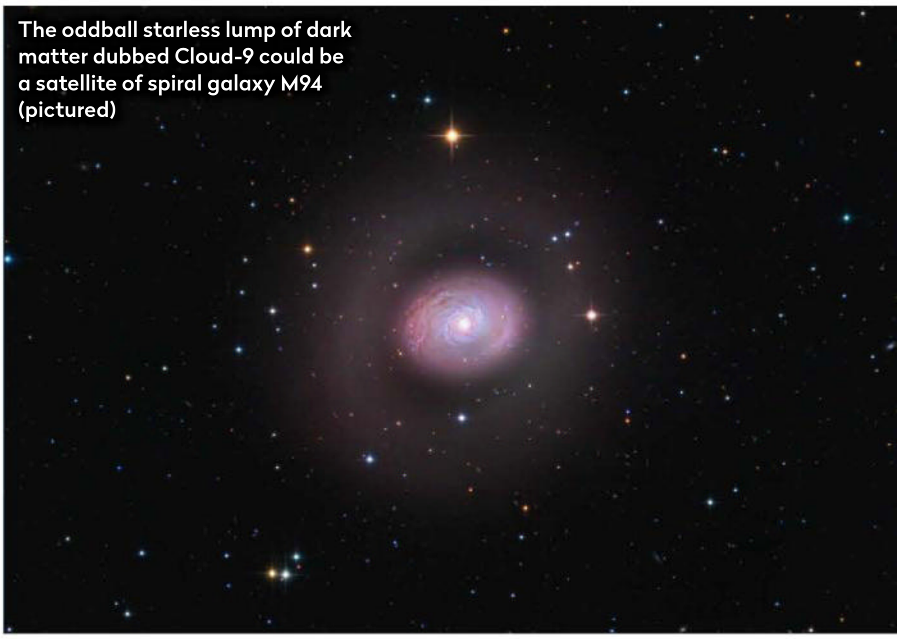
Gas rich, star poor

This new discovery, charmingly called 'Cloud-9' by the discovery team, could be a satellite galaxy of M94, but if so it's a strange one. The deepest imaging we have so far shows no signs of any stellar light at a position corresponding to the radio source, though given the data we have in hand a small luminous galaxy might still be lurking, hidden at the cloud's centre.

The modelling done in this new paper about the discovery suggests that, assuming no stars are found, it could have a mass of perhaps five billion times that of the Sun – small for a galaxy, though not unprecedented. The material in it is slightly more spread out than predicted, a discrepancy Benítez-Llambay and Navarro explain by suggesting that these objects may have a different distribution of dark matter than a 'normal' galaxy of the same size does. The galaxy may also be a bit more massive than otherwise expected.

"Assuming no stars are found, it could have a mass of five billion times that of the Sun – small for a galaxy, though not unprecedented"

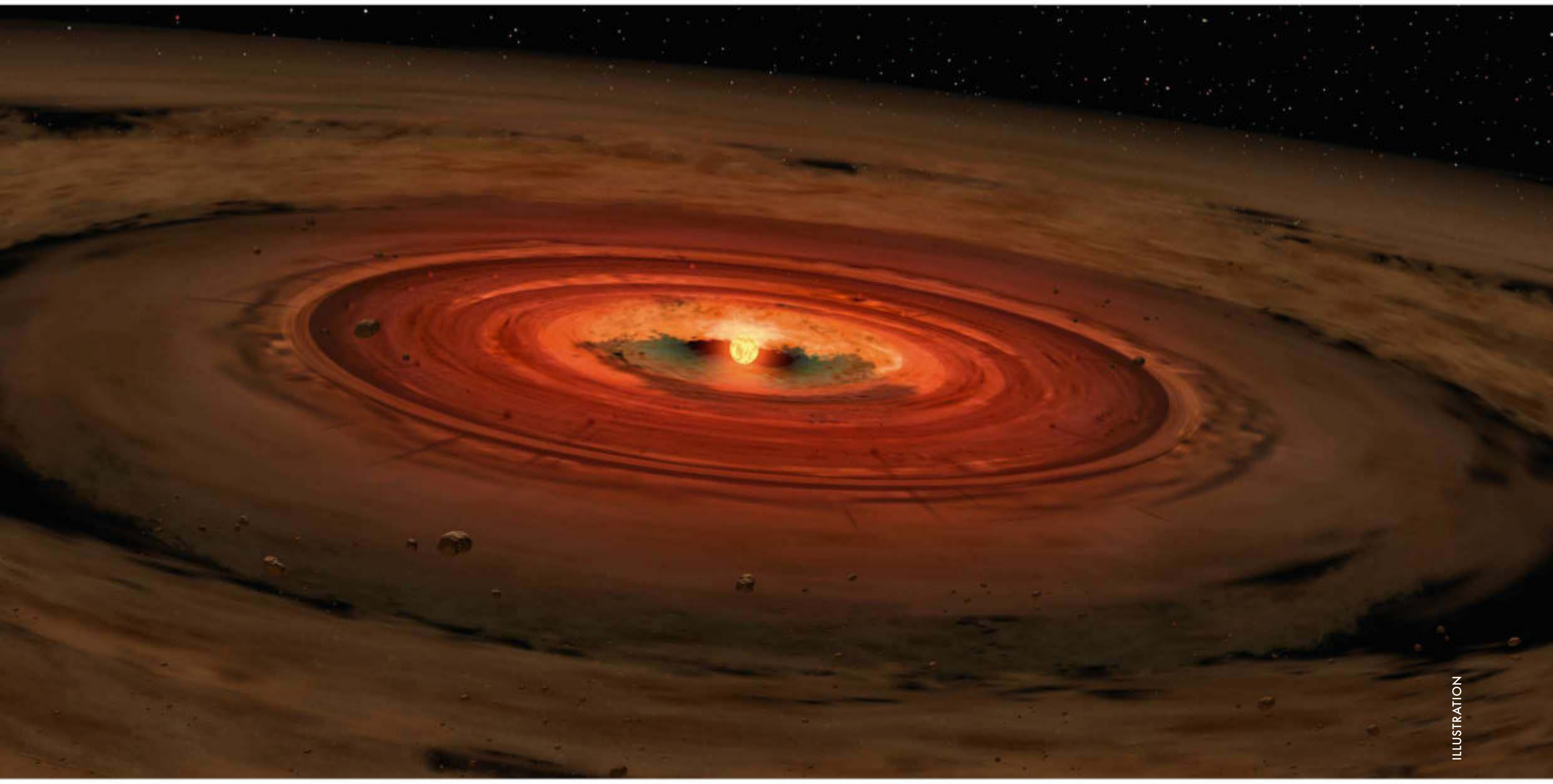
This is undoubtedly an exciting discovery, and I'm sure that telescopes will soon be swinging to observe Cloud-9. Top of the authors' wish list will be to get higher-resolution radio observations. A single dish like FAST cannot match the performance of an array, and the MeerKAT radio telescope in South Africa has the capability to give us a much sharper view of how the gas is distributed, and even that is just a precursor to the much larger Square Kilometer Array. Long-exposure imaging could show gas in the cloud's outskirts, and Hubble would be ideal to look for any stars that exist. Expect to hear more from Cloud-9 soon.



The oddball starless lump of dark matter dubbed Cloud-9 could be a satellite of spiral galaxy M94 (pictured)

Chris Lintott was reading… *Is a Recently Discovered HI Cloud near M94 a Starless Dark Matter Halo?* by Alejandro Benítez-Llambay and Julio F Navarro **Read it online at: arxiv.org/abs/2309.03253**

INSIDE THE SKY AT NIGHT



▲ How are we able to look inside the planet-forming discs around stars? That's one of the questions frequently fired at the *Sky at Night* Question Time panel member Claire Davies

Claire Davies from October's *Sky at Night* Q&A special answers five questions she's frequently asked about how stars and planets form

I use some of the highest-resolution observing facilities on Earth to study how stars and their planets form. Five of the questions I'm frequently asked about my research are:

How long does it take to form a star?
The process starts with an initial collapse of material in a molecular cloud, trigged by gravity, and ends when hydrogen fusion ignites in the star's core. How long this process lasts depends on the mass of the star. For stars like the Sun, it takes a few tens of millions of years, while higher-mass stars are formed much more quickly and lower-mass stars take much longer. Regardless of the mass, the process is rapid in proportion to a star's lifetime: if you condensed the lifetime of a star down to the lifetime of a typical human, the formation process would only take around three months!

Do planets form at the same time as stars?
Our Solar System's planets, and most extra-solar planets that have so far been discovered, are 'first generation' planets: they formed from the same collapsing material as the star. During collapse, there is a battle between gravity and rotation, which results in the formation of a circumstellar disc. The material in these discs is what collapses or coalesces further to form planets.

Do all stars form planets?
It ultimately depends on the lifetime of its disc. We see some protostars in very young star-forming regions which lack discs. However, we aren't yet able to investigate whether planets have already formed around these stars or whether the disc dispersed before they had time to.

Just because planets form in orbit around a star doesn't always mean they'll stay there either. In long-lived discs, planets may interact with neighbouring disc material, resulting in an orbital tug-of-war. Planets may drift inwards onto increasingly shorter orbits and some of these may end up being engulfed by their star. Others may encounter more massive protoplanets during their migration through the disc and be thrown out of their system altogether.

Claire Davies is a lecturer in physics and astronomy at the University of Exeter

Protoplanetary discs look dark in Hubble and JWST images. How do astronomers peer inside them?
Discs appear dark in images taken in visible light because they block out this light from their host stars. To peer inside, we use instruments which are sensitive to longer wavelengths of light. I'm interested in the inner regions of discs, where temperatures reach up to 1,000° Celsius or so. I therefore use infrared telescopes which are sensitive to light emitted by material at these temperatures. Some of my colleagues are interested in the densest portions of the disc, which are much cooler (down to around –250° Celsius) so they use submillimetre telescopes, like ALMA.

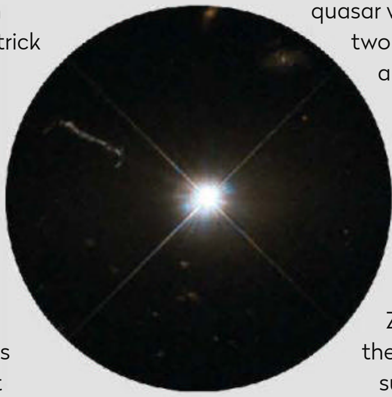
What do we still not know about how stars and planets form?
Lots! One thing that I find most intriguing is the architecture of our own Solar System: all the planets orbit the Sun in the same direction and in the same plane, which also matches up with the Sun's equator. But other planetary systems are far from lined up. Some extrasolar planets have very steep orbits or even rotate in the opposite direction to their stars. Some planetary discs are significantly warped or have rings which are inclined at different angles. We don't fully understand why or when these misalignments occur, or how frequently they arise.

Looking back: The Sky at Night

24 November 1976

In *The Sky at Night* on 24 November 1976, Patrick looked at quasars, cosmic objects that look like stars but behave very strangely.

They were discovered in 1963 when a radio source that had no obvious visible counterpart was matched with what at first appeared to be a faint blue star.



▲ **Quasi-stellar radio source (shortened to 'quasar') 3C 273 in the Virgo constellation**

The following year, astronomers were able to take a spectra of quasar 3C 273 when it was occulted by the Moon. This showed the emissions lines were shifted by 15.8 per cent, one of the biggest shifts ever seen up to that point. If it was due to the motion of the object itself, it meant the quasar was travelling at a staggering 47,000km/s. If the expansion of the Universe was responsible, it meant the quasar was an astounding two billion lightyears away and brighter than an entire galaxy. At the time there was no known mechanism that could explain either option.

In 1964, Edwin Salpeter and Yakov Zeldovich put forward the theory that it was superheated gas falling onto the supermassive black hole at the centre of a galaxy that causes quasars to glow. It was controversial – at the time, black holes were still seen as theoretical – but observations of 'dead' quasars in the hearts of other galaxies and modelling of these regions soon backed the theory up.

Today, more than a million quasars have been found, up to 13 billion lightyears away, granting astronomers a window into the earliest Universe.

The Sky at Night meets *The Infinite Monkey Cage*

The Sky at Night teams up with popular Radio 4 programme *The Infinite Monkey Cage* to talk amateur astronomy. Maggie, Chris and Pete join Brian Cox, Robin Ince and Dara Ó Briain to discuss their love of stargazing, their favourite kit and what you can see in the night sky. And they discover the astronomy you can do when it's cloudy, including 'listening' to space.

BBC Four, **13 November**, 10pm (first repeat will be on BBC Four, **16 November**, 7pm)
Check www.bbc.co.uk/skyatnight for more up-to-date information

▲ **The team join Brian Cox and Robin Ince for a *Monkey Cage* crossover**

Emails – Letters – Tweets – Facebook – Instagram – Kit questions

INTERACTIVE

Email us at **inbox@skyatnightmagazine.com**

MESSAGE OF THE MONTH

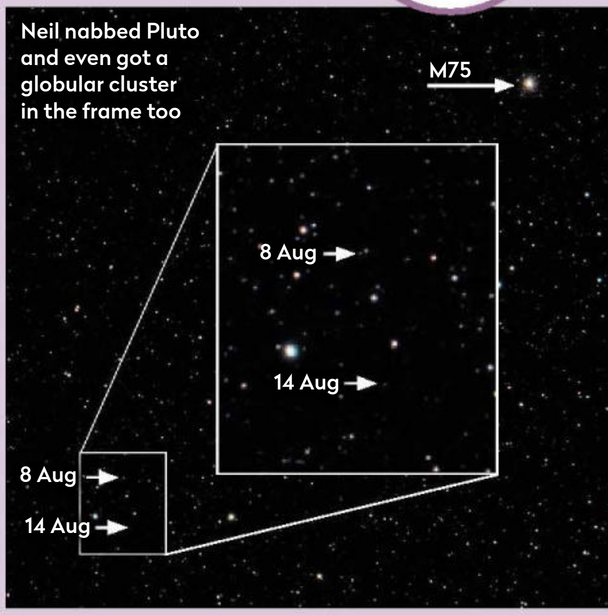
This month's top prize: two Philip's titles

The 'Message of the Month' writer will receive a bundle of two top titles courtesy of astronomy publisher Philip's: Nigel Henbest's *Stargazing 2024* and Robin Scagell's *Guide to the Northern Constellations*

Winner's details will be passed on to Octopus Publishing to fulfil the prize

Good spot!

I decided to take you up on your 'Sky Guide challenge' in the July 2023 issue to image Pluto, and I'm delighted with what I captured. After taking my first photo on 8 August, I was desperately hoping for another clear night before Pluto moved out of the frame with M75. Fortunately, I got my opportunity a few days later on the 14th! It was thrilling to follow in the footsteps of Clyde Tombaugh, over 90 years later, by comparing both images to track the movement of Pluto. The image is a stack of 94 60-second exposures taken with an Altair Astro 60EDF with 1x flattener and a ZWO ASI533MC-Pro camera fitted with a UV/IR cut, sitting on a Celestron AVX mount. Capture, stacking and processing was done with NINA, Astro Pixel Processor, StarTools and Photoshop. The top arrow shows Pluto's position on 8 August, the bottom arrow on 14 August. Globular cluster M75 is also seen to the upper right.
Neil Goddard, Witney, Oxfordshire

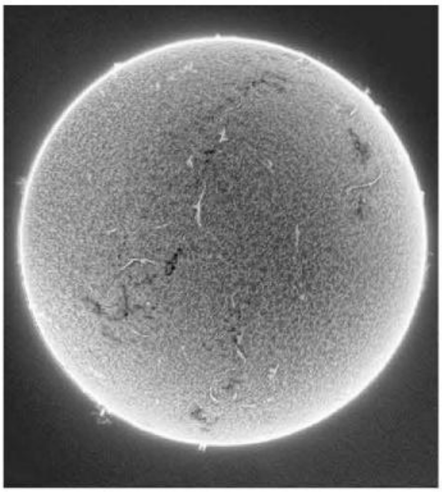


Neil nabbed Pluto and even got a globular cluster in the frame too

What a great find, Neil! Tiny, faint Pluto can be really tough to track down, so well done on capturing and locating it within this busy star field. **– *Ed.***

Tweet

SkyWatcher (Dave)
@SkyWatch07 • 9 Sept
Saturn is 1.3 billion km away from my patio, but my Dobsonian (10-inch) allows me to see the gas giant instantly. Shot in misty conditions two nights ago.
#Astrophotography #Saturn @skyatnightmag



▲ **With solar activity on the up, it's an exciting time for Sun imagers like Anton**

Sun-day best

I've been fine tuning my old Coronado PST and have been getting some of the best results I've had in recent years, both visually and photographically. My solar scope has had a new lease of life as a result! Here is a double-stacked image of the Sun taken on 29 August.
Anton Matthews, via email

Supernova update

I was looking online for images of supernova 2023ixf and came across your article 'Bright supernova SN 2023ixf in M101 the Pinwheel Galaxy' (**www.skyatnightmagazine.com**). Most of the photos were taken close to the time the supernova was first observed in May 2023, but I took this photo (next page) later, on 4 September. It seems that the supernova is turning more red-orange as time goes on, and I thought this would be interesting for others to see. The image is made up of 74 exposures of 60 seconds each, taken with a Stellarvue 125A and Starizona Apex

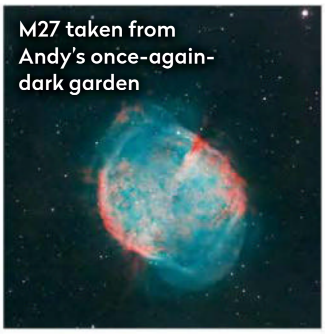
Rick noticed some changes in May's superstar supernova

0.65x reducer, and a QHY5III178 OSC camera, with gain set to 15 and an offset of 20.

Rick Clevenger, North Carolina, USA

Dark arts

Here (below) is my picture of M27 the Dumbbell Nebula, taken in my back garden in early September. I know it isn't spectacular or unusual, but this is the first photo I've been able to take for some time. The local council had installed high-intensity LED streetlights about 18 months ago, which floodlit most of my garden and took it from Bortle 5 to 9! After battling with the council for a long time and having to get some superb support from my local councillor, bespoke light shades were finally fitted about two weeks ago to coincide with the September heatwave. It's a stack of 50 four-minute exposures with no filters, using a Celestron Edge 8 HD at f/7, a ZWO ASI294 MC Pro camera and an EQ6-R mount guided with an OAG. I was so excited to be back out imaging, I just stacked everything immediately to see what they would produce! I used Astro Pixel Processor ▶



M27 taken from Andy's once-again-dark garden

ON FACEBOOK

We asked: Are you excited to see NASA's Artemis programme return humans to the Moon?

Brian McMullan Yes! Get a new *13 Minutes to the Moon* podcast going!

Steven Jackson I am, but I suspect, like the Apollo programme, it will be cut short due to insufficient funds.

Gregory Ralph I am, I just wish we were the other side of a successful Artemis II mission so we could concentrate on the landing!

Dougies Nick Not really. It's just a rehash of the Apollo missions. They're not going to do anything new from what I've heard.

Pennie Ley Yes. Because it might shut people up about "we never went there and you can't get there"! But seriously, I am excited because my name is on one of the microchips and I'm trying to get my schoolkids interested in space as a job.

Angie Thorne Yes, just wish it was sooner. I was totally hooked on the Apollo missions.

SCOPE DOCTOR

Our equipment specialist cures your optical ailments and technical maladies

With **Steve Richards**

Email your queries to
scopedoctor@skyatnightmagazine.com

Some people use webcams with a telescope and stack the best frames to create lunar and planetary images. Can I do the same with my Canon EOS Ra camera and its video function?

MAXWELL TAGGART

▲ Stacking lots of single frames might beat using video with a Canon EOS Ra

This method of capturing images, sometimes known as 'lucky imaging', is very effective on Solar System objects as some of the image frames will contain good data, free from the effects of poor seeing and these are automatically used in the stacking process.

The Canon EOS Ra is a mirrorless DSLR camera designed specifically for deep-sky imaging by using a modified infrared (IR) filter that allows more of the hydrogen-alpha wavelength of light to pass through to the sensor. However, the extended IR range of the filter will impart a false red hue to day-time photographs and Solar System objects, so it will help to correct for this if you place a suitable IR-cut filter in the light path and use a custom white balance setting for your planetary and lunar images.

Although you can use the video function, it would be a good idea to try capturing lots of individual still images and stacking them as an alternative, as this can yield better-quality, less compressed data.

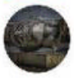
Steve's top tip

What is focal length?

The focal length of a lens or convex mirror, as used in refractor and reflector telescopes respectively, is the point at which light from a celestial object is brought to best focus. Different focal lengths are used for specific purposes, as focal length has a profound effect on observations. Longer-focal-length scopes have a greater magnification and a narrower field of view than a shorter-focal-length telescope using the same eyepiece. Eyepieces also have a focal length as they contain lenses; a shorter-focal-length eyepiece has greater magnification and a narrower field of view than one with a longer focal length.

Steve Richards is a keen astro imager and an astronomy equipment expert

Instagram



tanya_capturedmomentimages • 24 September

1st aurora of the season for me and what a show she put on tonight. She danced beautifully. Never have I seen the reds and greens so bright with the naked eye. Magical to watch this with my hubby. Great Orme. Llandudno. #aurorborealis #welshskies @bbcskyatnightmag

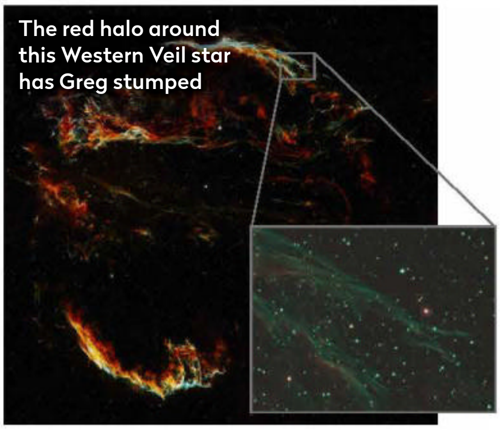
▶ to stack, then PixInsight and Lightroom to finish off. It's great to be back enjoying the jewels of the night sky and I'll hopefully be adding more to this in the near future!

Andy Taylor, Redditch

Veil of mystery

I finally finished my first mosaic ever with the Cygnus Loop as the target. It nearly melted my PC as each layer was over 750MB! It's comprised of six panels each, with 21 five-minute exposures using a ZWO ASI183MC Pro with an Optolong L-Enhance filter through my Sky-Watcher Evostar ED72. Anyway, on the 'tail' of the Western Veil there are two similar red stars. In my image, the one at the tip of the tail has a distinct red halo around it which, once processed, became very prominent. It's a mag. +10.6 star located at RA 20h 46m 33s and dec. +30° 09' 55". I haven't seen it like this in other images and wondered if it was an artefact from the L-Enhance filter. Has anyone else seen a similar thing with this star?

Greg Sanders, via email



The red halo around this Western Veil star has Greg stumped

SOCIETY IN FOCUS

Mansfield & Sutton Astronomical Society (MASA) was founded in 1970 by David Collins, who is still a member. After years of construction by volunteers, our observatory was officially opened in 1986 by the 13th Astronomer Royal, Sir Graham Smith. At the observatory today, about 140 members deliver open evenings, solar days, courses and off-site events reaching approximately 3,000 people a year.

Benefits to our members include the use of the observatory facilities, a monthly magazine, guest lecturer visits and social gatherings. This year, a new mirror set is being installed in our 24-inch Newtonian telescope. We also have a radio astronomy section which includes meteor and solar flare detection, Jupiter/Io system emissions and the measurement of hydrogen in the Milky Way.

The jewel in the crown will be our new science discovery centre and planetarium, which has a planned completion date of November 2024. This will enable us to reach 20,000 members of the public per year. With the support of Ashfield District Council, we have received funding from the Towns and Levelling Up Funds, and grants from the Wolfson, Garfield Weston and Foyle Foundations and the National Lottery Heritage Fund. Contributions are gratefully received though our donations page at www.totalgiving.co.uk/appeal/sciencediscoverycentre.

Stephen Binns, Communications Officer, MASA

▶ **sherwood-observatory.org.uk**

ILLUSTRATION

▲ **MASA members eagerly await the opening of their brand new science centre**

BBC Sky at Night MAGAZINE

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We pick the best live and virtual astronomy events and resources this month

WHAT'S ON

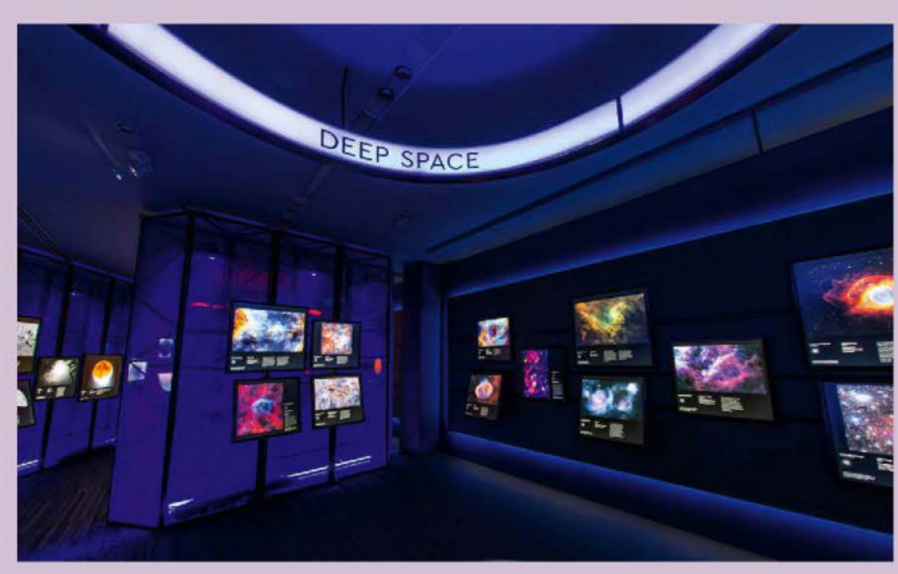
WinterFest Astro Star Party 2023

Kelling Heath Holiday Park, Holt, Norfolk, 9–13 November

Birmingham Astronomical Society's own star party returns for its eighth year, and with the event taking place in the park's dedicated 'red field', stargazers and astro imagers can look forward to four glorious nights of unspoilt night vision. Open to all veteran and aspiring astronomers.

winterfestastro.co.uk

PICK OF THE MONTH



▲ Give your eyes a treat and visit Greenwich to see this year's stunning astro images

Astronomy Photographer of the Year 2023

National Maritime Museum, Greenwich, until August 2024

The National Maritime Museum once more plays host to some of the finest astro images you'll ever see, as it presents its annual display of the best entries submitted to this year's Astronomy Photographer of the Year competition. You might have seen the winning photos in *BBC Sky at Night Magazine* or online already, but the exhibition showcases all the shortlisted images from all the different categories and more, making it a must-visit, whether you're an astrophotographer yourself or just a space nut generally! Admission is £10 for adults, concessions £6.50, kids aged 4–15 £5, under 4s free.

rmg.co.uk/whats-on/astronomy-photographer-year/exhibition

Family Space Night

Bredhurst Village Hall, Gillingham, Kent 10 November, 8pm

Mid-Kent Astronomical Society hosts a fun-packed family evening that includes a beginners' guide to the night sky, hands-on activities for younger children and the chance to do some live observing though members' telescopes. £3 for adults, £1 for members, under 18s free.

midkentastro.org.uk

Unidentified Flying Objects

Nazarene Theological College, Didsbury, Manchester, 13 November, 7pm

West Didsbury Astronomical Society welcomes Dr Steve Barrett, a senior research fellow from the University of Liverpool's department of physics, who'll be sorting science from myth when it comes to all things UFO and UAP. All welcome. Free entry.

wdas.uk

Detecting Life on Exoplanets

University of Wolverhampton and via Zoom, 20 November, 7:30pm

Astronomer and author Martin Griffiths visits Wolverhampton Astronomical Society to talk about exoplanets and astrobiology, in particular what JWST might tell us about potential life on other planets. Non-members £2.

wolvas.org.uk

Building the ETMO Observatory

Kyle Academy, Ayr, 27 November, 7pm

Completed in 2022, the Eric Tomney Memorial Observatory is owned by the Astronomical Society of Glasgow and named after its former president. In this talk, Dr Andrew Conway will tell the story of its conception and construction. Entry free if it's your first visit.

ayrastro.com

White Dwarf Pulsars

Queen's Buildings, University of Cardiff, 30 November, 7:30pm

In this talk for Cardiff Astronomical Society, Dr Ingrid Persoli from University of Warwick's physics department will discuss these most curious of cosmic objects, only two of which have ever been discovered. All welcome.

cardiff-astronomical-society.co.uk

BRIAN BOGGENPOEL, NATIONAL MARITIME MUSEUM

FIELD OF VIEW

From moonwalk to catwalk?

Spacesuit design is moving into the realms of fashion, says **Jonathan Powell**

▲ **Spacesuits left to right: Escafandra estratonáutica (stratonautical suit, 1935, Spain); SK-1 (1961–63, USSR); Gemini 8 (1966, USA); Extravehicular Mobility Unit (1980s–2000s, USA); SpaceX (2020; USA), Artemis (2023, USA)**

While astronomers may not typically lead in the fashion stakes, there is one closely linked sphere that has moved with the times – that of spaceflight, the astronaut and, in particular, the spacesuit.

The basic template for the early spacesuit would have been drawn from attire affording protection for those working in similarly testing environments, such as the deep-sea diver and the aircraft pilot. Clothing for both of these roles was functional and robust, with a proven track record of achieving what the suit was designed to do.

However, after rigorous testing of suits like these, doubt must have crept into the mind of even the most disciplined of astronauts. A leaky diving suit could potentially see its wearer pulled up from the watery depths quickly enough to save them, but once you've ventured into space, the options for survival in one are more limited or, more accurately, nil.

As the Soviet Union and the USA jostled for the prize of putting the first human not just in space but on the Moon, NASA and its foreign counterpart grappled with one of the biggest headaches: potential damage to the membrane of the spacesuit while in space. NASA had constructed a vacuum chamber to test its spacesuits. Dubbed the 'Moon Room', it was apparent early on that the agency was more interested in the long game.

With Sputnik-1 already in the bag for the Soviets, Yuri Gagarin's spacesuit, the SK-1 (standing for the Russian Skafandr Kosmicheskiy, literally translated as 'diving suit for space') became the first spacesuit ever used. With the Americans close on their heels, the Moon loomed even larger on the horizon, and it's here that NASA ramped up their efforts.

The Mercury, Gemini and subsequent Apollo programmes put the US firmly back on the map, with the Mercury spacesuits of the late 1950s and early 1960s looking sharp and dapper, and certainly iconic for any science-fiction writer of the time. Shiny silver in appearance, the Mercury 7 were in town with a more fashionable but still functional spacesuit.

The Mercury spacesuits were to be only worn inside the spacecraft, while the Gemini suits were designed for tethered activity outside the capsule. The Moon, though, demanded greater protection against extreme temperatures and the harsh lunar environment, and with the spacesuits now fitted with their own life-support system, a new era had begun.

As private business has entered the field of spaceflight in the past few decades, a shift in approach to spacesuit design, manufacture and appearance has become evident. As the desire to progress to a 'next generation' look commenced, the spacesuit has turned into more of a product. And with crewed missions to the Moon and Mars on the radar, a new long game has arrived.

The primary objective of the spacesuit is to protect the person within, but technological advances have allowed the suit to outgrow that objective, turning the cumbersome look of yesteryear, that leaned so heavily on safety, into a smarter design. And while the look of the spacesuit has changed, it's only down to the advances in science that underpin the fabric.

SARAH MAXWELL/FOLIO

Jonathan Powell is a freelance writer and broadcaster, and the astronomy columnist at the *South Wales Argus*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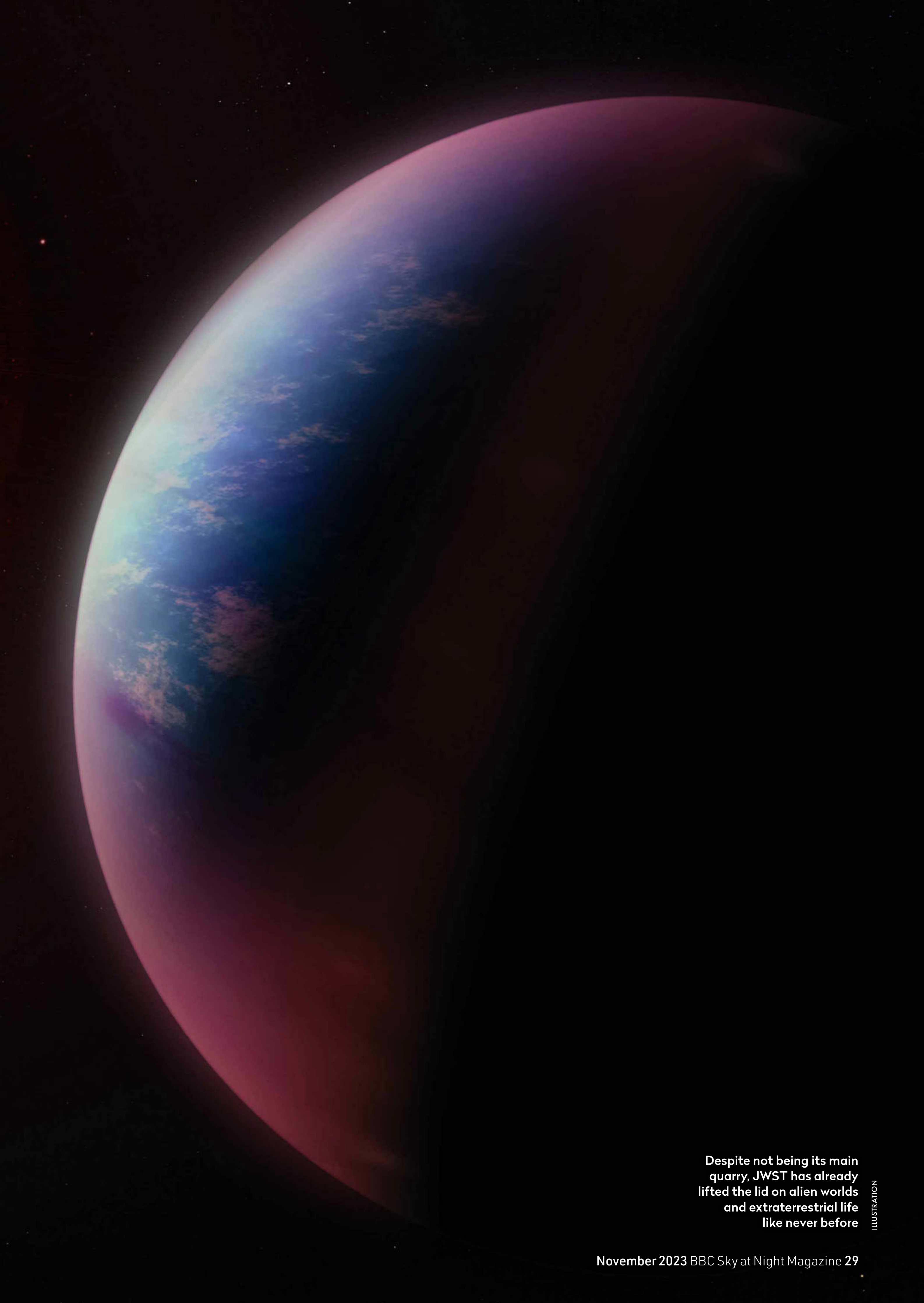
ELEN11/ISTOCK/GETTY IMAGES

Exploring **alien worlds** *with the* **JWST**

The infrared observatory is delving deep into the atmospheres of every kind of exoplanet, as **Ezzy Pearson** finds out

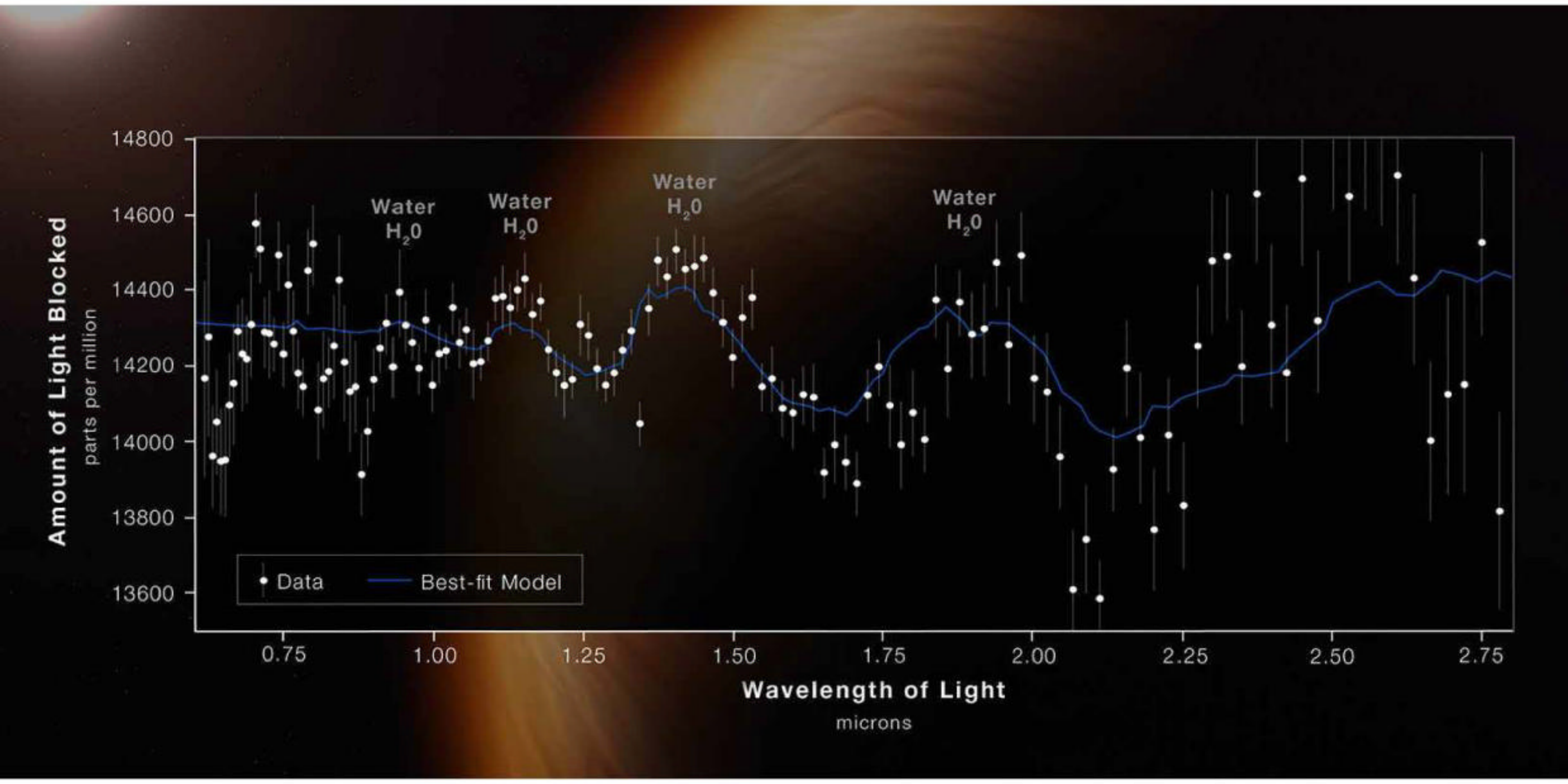
In the 1980s, as NASA was putting the finishing touches to the Hubble Space Telescope, discussions began to turn to what the agency's next grand orbital observatory would be. The design they came up with was a huge, 6.5m-wide infrared observatory that could peer back through distance, dust and even time to view the dim light of the earliest galaxies, and which we now know as the James Webb Space Telescope (JWST).

At the time of those first discussions, humanity had yet to even find a hint that there were planets orbiting around other stars. That changed in 1992, when it was announced that the first-ever confirmed alien world had been found around PSR B1257+12, sparking three decades of exoplanet exploration. ▶



Despite not being its main quarry, JWST has already lifted the lid on alien worlds and extraterrestrial life like never before

ILLUSTRATION



▲ **Astonishingly precise measurements of the starlight from WASP-96b revealed a distinct signature for water vapour**

▶ Astronomers have now catalogued over 5,000 verified exoplanets, with as many more awaiting official confirmation.

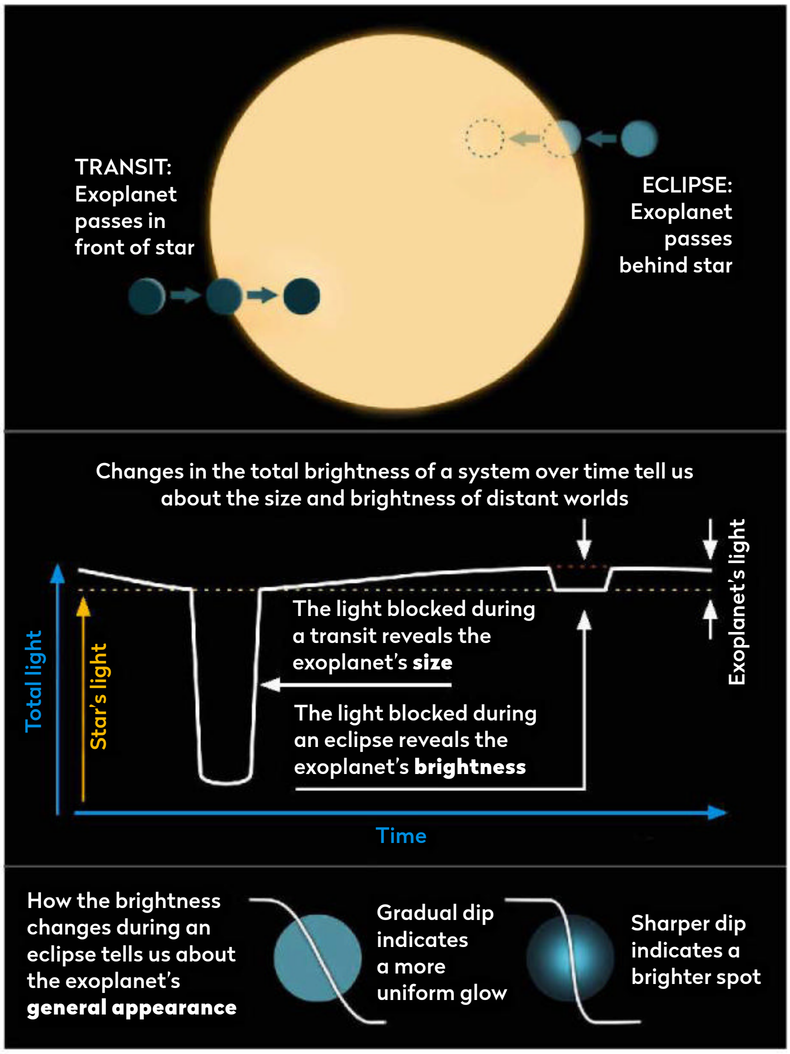
For most of these worlds, however, we have only a few scant details – perhaps only how long they take to orbit, their size and their mass. This is enough information to roughly gauge a planet's density and so reveal if it's mostly made of heavy rock or less dense gas; but it doesn't tell you what the planet is actually like. This is where JWST steps in. Though it wasn't designed for it, the telescope can look into an exoplanet's atmosphere and even pick out planets themselves as they orbit around their host star. What's more, it can do it around more types of planet than ever before.

"JWST is looking across the whole range of exoplanet sizes," says Hannah Wakeford from Bristol University. "We have things that are rocky and smaller than Earth, all the way up to gas giants twice the size of Jupiter."

Sifting through starlight

Wakeford and her team investigate what are known as transiting exoplanets. These planets pass in front of their star (from the perspective of Earth), blocking out a tiny bit of the star's light. Most exoplanet-hunting missions, such as NASA's Kepler or TESS (the Transiting Exoplanet Survey Satellite), find their planets by looking for tiny dips in a star's brightness. Once these have pinpointed the location of a likely planet, JWST can slew in for a closer look.

"With JWST we're specifically trying to measure the planet's atmosphere," says Wakeford. "We can do that by looking at the light shining through that atmosphere. Imagine a picture from the International Space Station looking through Earth's atmosphere



▲ **Even brightness changes of just two per cent allow JWST to glean a wealth of information about an exoplanet's size, brightness and general appearance**

NASA/ESA/CSA AND STSCI, NASA/JPL-CALTECH (R. HURT/IPAC), JOHAN63ISTOCK/GETTY IMAGES, NASA/JPL-CALTECH/H. KNUTSON (HARVARD-SMITHSONIAN CFA)

If JWST could see us, it would be the first telescope that could tell Earth apart from worlds like Venus

Eyes on Earth

Our own Solar System highlights why planetary atmospheres are so important

It may be one of the most capable exoplanet investigators ever devised, but there are many planets JWST can't see, including those like our own. Earth is far too small for direct imaging, and while JWST can see Earth-sized planets via the transit method, it can only do so around dim stars. To find our planet against the bright Sun would require observing as many as 100 transits. Given that Earth transits the Sun only once a year this would mean a century of observation, just for one planet.

Even if JWST could see our planet, astronomers would struggle to understand what they were seeing. "If we could measure our Solar System we would see Earth and Venus and make the assumption they were both the same, when they are most definitely not," says Wakeford.

It's an easy mistake to make. Venus and Earth are roughly the same distance from their star, and the same size and density. And that's all we know about most exoplanets. Only when comparing their atmospheres do the real differences show. Earth's geological history has allowed it to maintain a nitrogen-rich atmosphere, temperate enough for oceans to form. Venus's volcanic past has resulted in an atmosphere that's almost entirely carbon dioxide, where the surface pressure is 92 times Earth's and temperatures reach 475°C.

Until now, planetary geologists have only been able to test their theories about such differences against the limited number of worlds in our Solar System. As JWST reveals more about exoplanet atmospheres, the more we grow our understanding of what chemistry and geology makes one planet end up like Earth and another like Venus.

at sunset. We're able to see an imprint of what the atmosphere is made of in the light we're measuring."

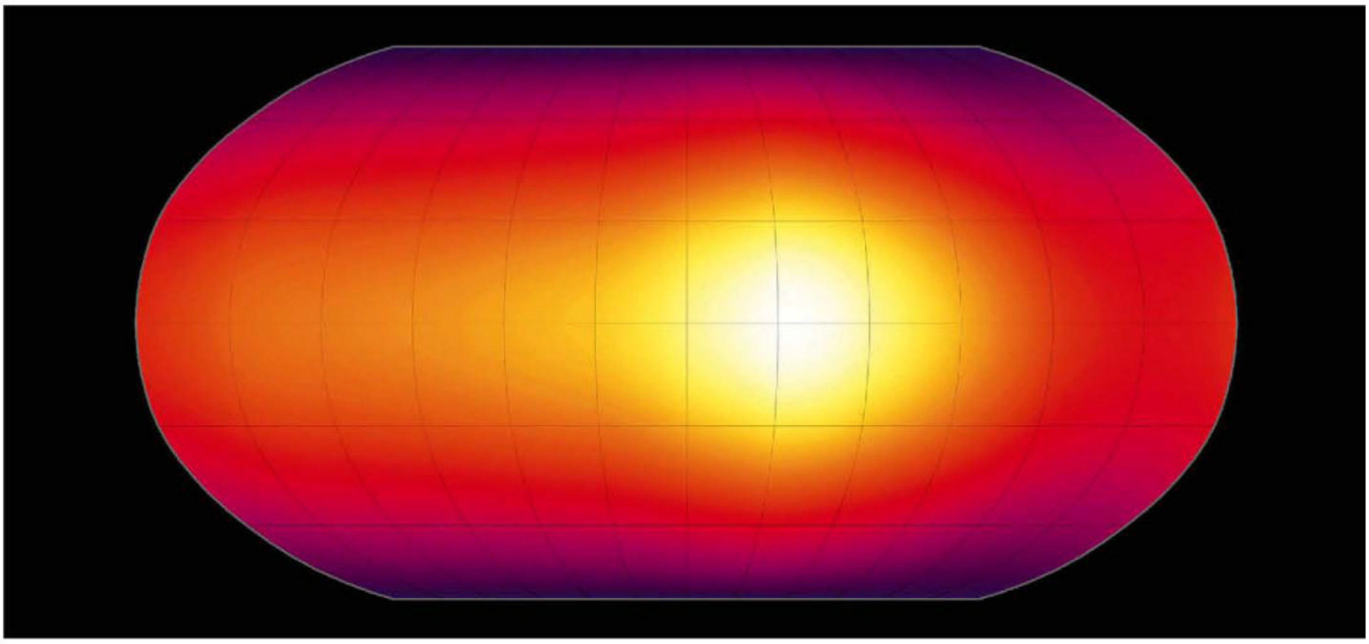
This imprint is left behind as the molecules within the atmosphere absorb some of the starlight as it passes through. The same type of molecule always absorbs the same wavelengths, leaving a dark band in the starlight that can be detected using a technique called spectroscopy.

JWST can detect a great many molecules, including water vapour, as was showcased in the atmosphere of WASP-96b and the first-ever spectra of an exoplanet discovered by JWST, back in July 2022. As well as being a key ingredient in the evolution of life, it is also a vital part of many geological processes. Knowing how much is out there on other worlds will help exoplanet scientists better understand how planets grow and evolve.

But there are many more things JWST can find in the skies of alien worlds, including carbon-based chemicals such as carbon dioxide and carbon monoxide, both of which it detected for the first time on WASP-39b last year.

"On Earth, we call those greenhouse gases because they absorb infrared radiation. Our atmosphere is filled with these gases, so it blocks that light. This is the first time we've been able to get spectroscopy of these carbon-based gases in the atmospheres of so many different planets," says Wakeford.

JWST is also able to observe a planet when it passes behind its star and becomes eclipsed. This produces a much smaller dip as the star blocks the ▶



▲ A map of gas gaint HD 189733b, showing differences in temperature across its surface, from analysing its eclipse and transit behaviour

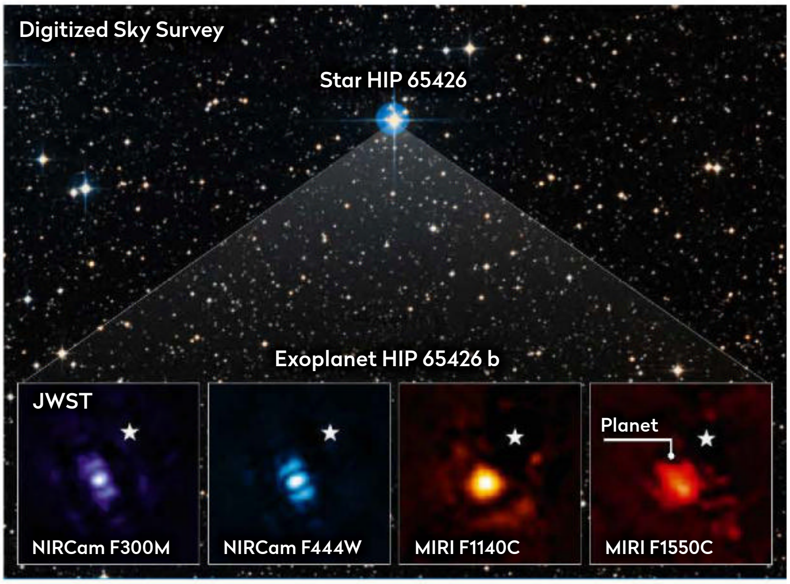
▶ infrared light given off by the planet. "Eclipses give us information on the thermal structures of the atmosphere, so how the temperature changes with altitude in the atmosphere," says Wakeford. "The temperature is really key for the chemistry that we're going to see."

Neither method is easy, however. "JWST was designed to pick up really faint galaxies in the early Universe," says Sarah Kendrew, who is part of the JWST operations team on behalf of the European Space Agency. "We're looking at nearby stars that are super bright. Exoplanet observations definitely push the boundaries of what we can do."

The dip astronomers are looking for is only two per cent, often less, of the total stellar brightness. To make it out, JWST must monitor from before the transit begins until after it ends, keeping the star centred to pixel-level accuracy. Each transit lasts six to eight hours, but if there is more than one planet in a system, observing runs could be even longer.

"The first year of observations had a programme that stared at a star for over 40 hours," says Kendrew. "Before launch we didn't know how stable the observatory would be over that kind of timescale, but actually it's incredible. Over 40 hours the biggest drift we saw was a fraction of a pixel. There's a programme coming up that wants to stare for over 55 hours."

While both transits and eclipses only observe planets indirectly via their effect on starlight, JWST is powerful enough to make direct observations of not just planets, but the discs of dust and gas that create them, known as protoplanetary discs. While planets only reflect optical light, they radiate out their own infrared light in the form of heat, albeit



▲ JWST's first-ever direct image of an exoplanet, gas giant HIP 65426 b, used coronography to block its star's light

Is there anybody out there?

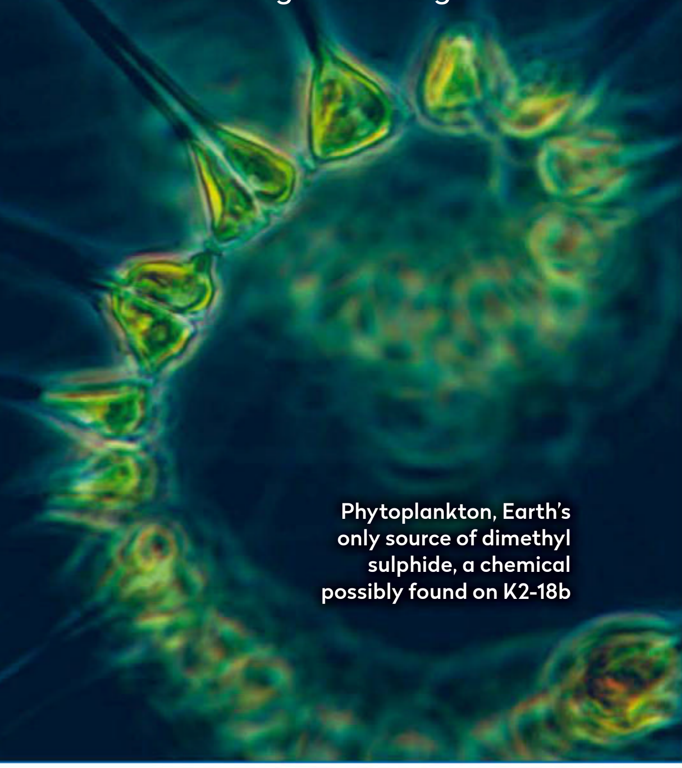
Alien life could be waiting in the cosmos, but we need to learn enough to recognise it

It's one of humanity's biggest questions, but could JWST be the telescope to tell us the answer?

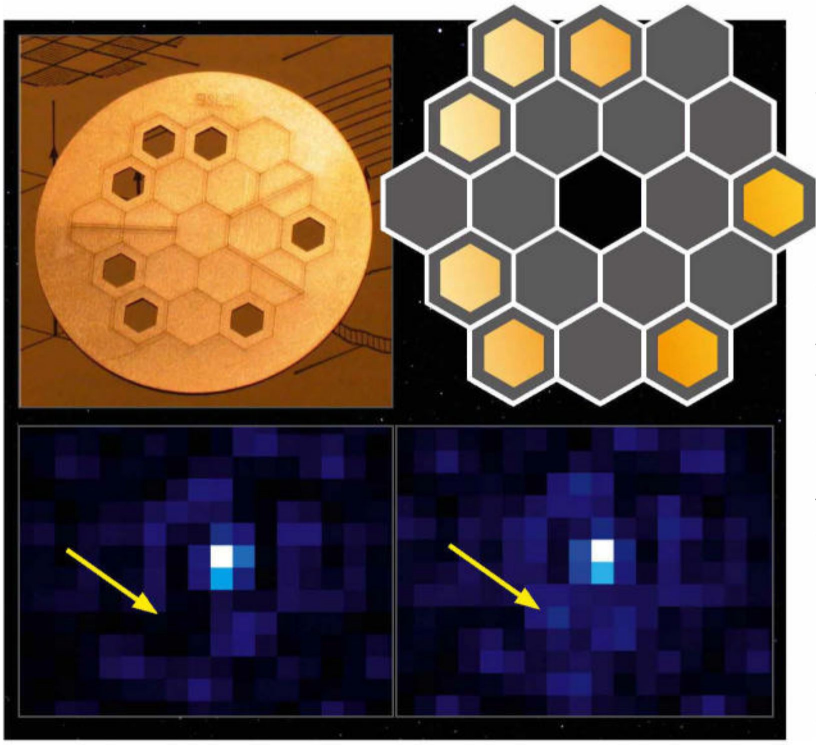
Unfortunately... no. To be observed using the transit method, a planet must orbit close into its star, where it will be bombarded by deadly radiation. Even if some organism did manage to evolve despite this onslaught, JWST is only able to identify the gases within a planet's atmosphere.

The limitations of this have already been highlighted by the potential sighting of dimethyl sulphide on K2-18b that was announced in September 2023 (read the full story on page 12). On Earth, the only known source of dimethyl sulphide is from living organisms, such as marine phytoplankton. However, K2-18b is a sub-Neptune planet, a category of exoplanet that's not well understood at all. We don't know what its atmosphere should look like in the absence of life well enough to say that this gas is definitely created by life rather than some other chemical or geological process.

"One of the key things in the search for life is that it takes everything," says Wakeford. "From understanding how the first stars formed, which then cause the supernova to create the elements that are making up these subsequent planetary systems, to whether it is important that galaxies are colliding, all the way down to understanding if the environment in which our Sun formed was a key ingredient for the prevalence of life on Earth. There's a whole story that we have to go through. The beauty of JWST is that it gives us access to every stage of that story."



Phytoplankton, Earth's only source of dimethyl sulphide, a chemical possibly found on K2-18b



◀ **Top: a mask blocking all but seven of JWST's mirrors allows the Near-InfraRed Imager and Slitless Spectrograph (NIRISS) to be used for interferometry. Bottom: simulated interferograms of a star on its own (left) and what it would look like with a planet (right)**

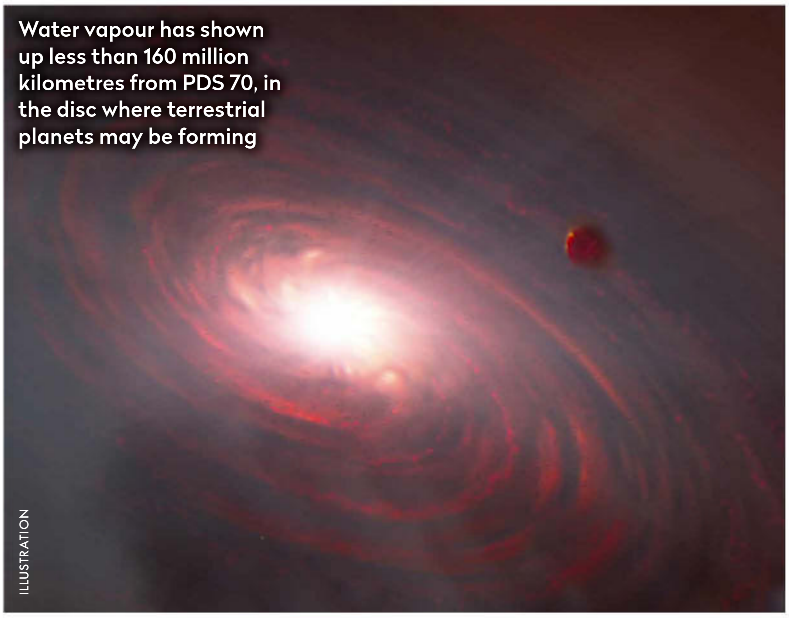
considerably less than the star. To prevent the planet being drowned out, JWST employs a method known as coronography.

Battling the glare

"We have special masks that do the coronography, where we do imaging but block out the light from the central star to image the discs or planets," says Kendrew.

This was how JWST was able to find water in the inner regions of the protoplanetary disc around the star PDS 70. This region is where rocky planets form, but previous studies suggested the star's radiation evaporated all the water away, so the discovery reveals that infant terrestrial planets could have access to water after all.

Ezzy Pearson is *BBC Sky at Night Magazine*'s features editor. Her book *Robots in Space* is available through History Press



Water vapour has shown up less than 160 million kilometres from PDS 70, in the disc where terrestrial planets may be forming

ILLUSTRATION

JWST has one final method of observing planets directly, using a different kind of mask with seven holes in it. This transforms the space observatory from one giant telescope into seven small ones, working together via a technique known as interferometry. As much of the light is lost, it can only be done on bright objects such as stars, but it improves JWST's resolution by up to two and a half times. This allows astronomers to resolve close-set objects that would otherwise appear as a single blob – such as a star and its surrounding planet or protoplanetary disc.

Both mask techniques can determine a planet's size, its orbit and even do spectroscopy on the atmosphere just like the transit method, but they do so on very different types of planets. The wider the separation between planet and star, the easier it is to differentiate the two. One planet observed by JWST, VHS 1256b, is four times further from its star than Pluto is from the Sun, but JWST was still able to detect silicate clouds rising like smoke through its atmosphere.

JWST's range is what makes it such a powerful tool. By looking at infant planets emerging from protoplanetary discs, all the way through to those much further on in their lifespans, JWST will help planetary geologists build their theories about how exoplanets grow and change over time.

But perhaps most interestingly, JWST can find which planets don't have an atmosphere at all. When it looked towards red dwarf TRAPPIST-1, it was expected to find a similar atmosphere to Venus. Instead it saw no trace of a thick carbon-dioxide-rich atmosphere. Meanwhile, the system's innermost planet reflects so much light, it suggests any atmosphere it ever had has been stripped away entirely. Such discoveries will help answer one of exoplanet science's most pressing questions.

"At what point does a rocky planet become a gas giant?" says Wakeford. "There's this transition of planets from rocks – terrestrial planets like Earth – to gas giants like Uranus and Neptune. Is there a cut off, where everything goes 'No, we're too big now. We're a gas giant'? We genuinely have absolutely no clue whatsoever, so that's one of the key goals of JWST, to look at those kinds of planets in a way we've never been able to before."

JWST has already made a good start on its quest to better understand exoplanets, having already observed 111 different planets, with another 65 lined up in its second year. Slowly but surely, it is building an inventory of what our Galaxy's planets look like, taking humanity one step closer to understanding how our world came to be.

NASA/ESA/CSA/A CARTER (UCSC)/THE ERS 1386 TEAM AND A. PAGAN (STSCI), WIRESTOCKISTOCK/GETTY IMAGES, ANAND SIVARAMAKRISHNAN (STSCI) X 2, NASA/ESA/CSA/J. OLMSTED (STSCI)

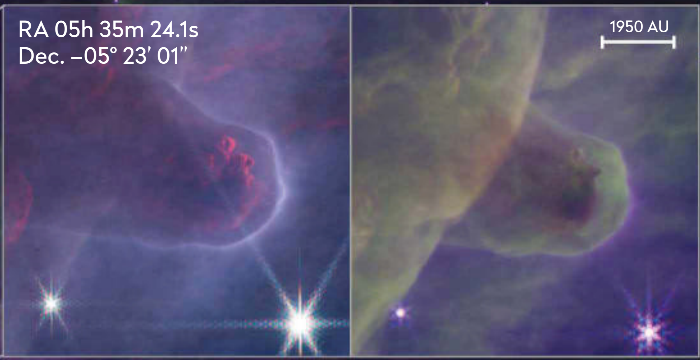
Explosion fingers

Only 500 to 1,000 years ago, an explosion occurred in the heart of a dense cloud of gas known as Molecular Cloud 1. The explosion sent out waves of material which struck the surrounding gas, heating it and causing it to glow, creating these bright 'fingers'. The red colour indicates areas of molecular hydrogen, but the green tinge seen at the tips of the fingers shows areas of hot iron gas.

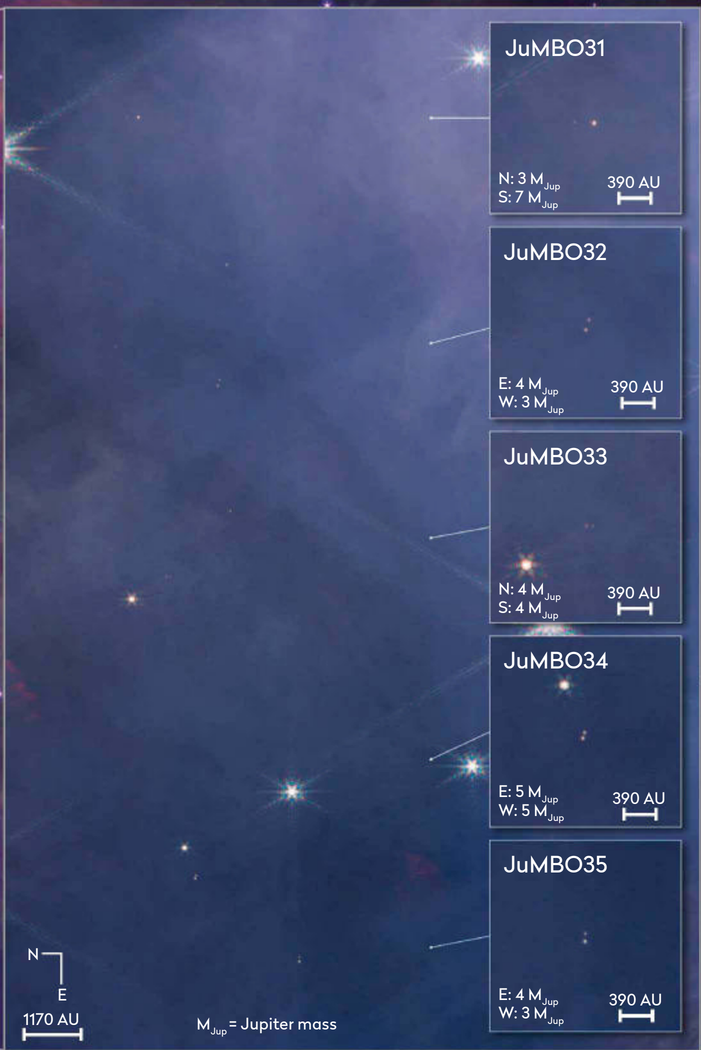
MAIN IMAGE: NASA/ESA/CSA/SCIENCE LEADS AND IMAGE PROCESSING: M. MCCAUGHRE/S. PEARSON X 4, TOBIAS KEMPF/500PX/ISTOCK/GETTY IMAGES

Deep inside the Orion Nebula

The James Webb Space Telescope has taken the deepest ever image of this favourite of the autumn and winter skies



Piercing the veil
JWST observes at various wavelengths to show different aspects of the nebula, such as these expanding fronts driven by forming stars. The shorter wavelengths, on the left, best show discs, outflows and stars. Meanwhile, longer wavelengths, seen on the right and in the main image, highlight the intricate filaments of dust.

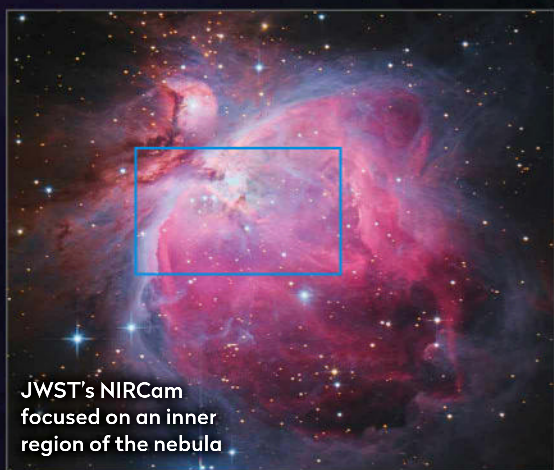


Neither star, nor planet
Astronomers combing through the images discovered dozens of pairs of large, gassy objects. They are around the mass of Jupiter, making them too small to have formed as stars according to our current theories, yet they are also free-floating, unlike most planets. These strange objects may have been ejected from their original planetary system, but intriguingly, mostly exist in pairs. How could they have survived the chaotic ejection process together? They've been dubbed Jupiter-mass binary objects (JuMBOs) and could be a new class of binary object.

This image of the Orion Nebula, taken using JWST's NIRCam instrument, reveals its finer details like never before. One of the most famous deep-sky objects in astronomy and a perennial favourite of astrophotographers, the nebula sits only 1,500 lightyears away and is the closest major star-forming region to Earth.

As with previous Hubble and Spitzer images, it focuses on an inner region surrounding the Trapezium Cluster of stars. The region is filled with gas and dust, which clumps together to form stars, only for the wind from those infants to carve out the gas creating a network of delicate structures. However, the dust obscures the view of most telescopes. Only JWST is able to pierce through.

The image is one of the largest JWST mosaics created to date. It reveals outflows of gas from stars, dusty planet-growing discs around young stars, and photodissociation regions where the radiation from massive stars shapes the chemistry of the gas around them. It is a treasure trove for astronomers investigating the early history of stars.



JWST's NIRCam focused on an inner region of the nebula

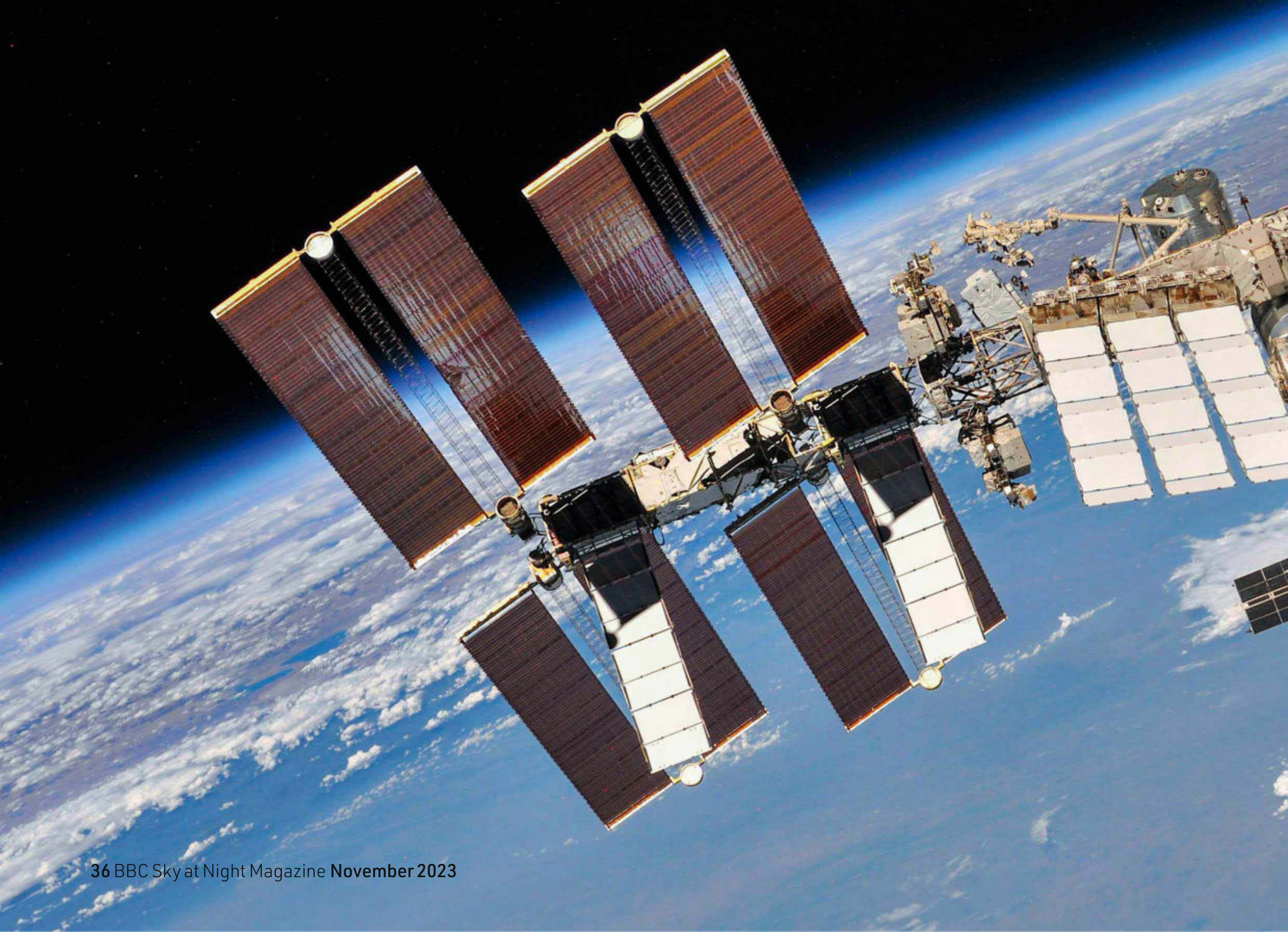
After the ISS

Approaching a quarter century in orbit, the International Space Station is nearer its end than its beginning. What comes next? **Sean Blair** finds out

GEOPIX/ALAMY STOCK PHOTO

All through the 21st century it has been above us, growing larger with the passing years. As the sunlight catches it, the sprawling structure becomes the brightest star of dusk or dawn.

The International Space Station's first segment was launched 25 years ago, on 20 November 1998. Since then, 15 further modules have been added to the initial foundation of Russia's Zarya FGB block and the ISS has grown into a 400-tonne behemoth. At 109 metres across, it is longer than a football pitch. Continuously occupied since 2 November 2000, more than 260 people from 21 countries have lived and worked on the Space Station. But it was originally designed for just 15 years in orbit. It can't last forever. So what happens next? ▶



The beginning of the end: after 25 years, the race is on to replace the ageing International Space Station

Where it all started: Russia's foundation module Zarya, launched on 20 November 1998

▶ The ageing station has generated negative headlines in recent years – micro-fractures triggering air leaks; a thruster misfiring that spun the ISS out of control; a greater number of space debris near-misses; coolant leaks from Soyuz and Progress craft, and a communications dropout this July – amid ongoing diplomatic strife between Russia and other ISS partners the US, the European Space Agency (ESA), Canada and Japan since Moscow's invasion of Ukraine.

But the severity of reported malfunctions is often overstated. As has been the case throughout the station's life, its international nature is a source of resilience. For instance, when NASA communications suffered a power cut in July, Moscow mission control stepped in. When Russian supply ships experienced coolant leaks – a Soyuz capsule in December 2022, then a Progress freighter in February – the US Dragon and Cygnus spacecraft remained available.

Countdown to a fiery finish

All but one of the international partners have signed on to keep the ISS flying until early 2031, with Russia's Roscosmos committing to 2028 so far (despite previous protesting). In practice, Roscosmos will be needed until the ISS's disposal, which is planned to take the form of a controlled deorbit. Depending on the solar-cycle-influenced density of the atmosphere, the ISS's altitude will be allowed to decay from the end of 2026 onwards so that, as seen from Earth, the ISS 'star' will grow brighter still.

Once it reaches as low as 333km (from its current 400km altitude) around the end of this decade, the ISS can no longer remain occupied. Into early 2031, thruster firings from the Moscow-controlled Zvezda service module will steer the station into atmospheric re-entry over Point Nemo in the South Pacific. This is Earth's remotest point, long employed as a watery spacecraft graveyard. The option of 'reorbiting' the ISS in higher orbit was rejected because the uncontrolled station is bound to be struck by debris at some point.

▲ Coolant leaks from Soyuz MS-22 docked to the ISS, after a suspected meteoroid hit in December 2022

"Simply put, it's getting old," explains Thomas Neil Sheasby, leading the engineering team of ESA's Low Earth Orbit Exploration Group.

"The ISS modules are being heated and cooled 16 times per day. There are micro-vibrations from dockings, reboosts and the crew moving around – all of this leads to fatigue. On the inside there's custom-made equipment that is becoming obsolete, making it harder to secure replacement parts.

"In space everything ages more rapidly: there's radiation damage, so items like solid-state drives in laptops get corrupted. Add to that the normal wear and tear of everything from air fans to water pumps. What we're doing now is performing an exercise to see where we can make do, where we still have spare parts, then coming up with a shopping list of what will need updating between now and 2031."

ESA's own ISS module – the Columbus laboratory – is holding up well, adds Richard Braeken, leading the agency's Sustaining Engineering Integration and

NASA X 4, ASSOCIATED PRESS/ALAMY STOCK PHOTO

▲ With its occupants similarly cooped up, a crowded jail smells much like the ISS, according to veteran astronaut Scott Kelly

What does the ISS smell like?

Unsurprisingly, it's tricky to keep a continuously occupied space station smelling sweet

The ISS, equivalent in volume to a Boeing 747, has been occupied continuously for more than 22 years. So what does it smell like? American astronaut Scott Kelly told *Wired* magazine: "I was touring the Harris County Jail [in Texas], and there's this room that smells like space station – combination of antiseptic, garbage, and body odour." He added that in the absence of gravity, bodily smells – such as farts – tend to linger. UK astronaut Tim Peake said it smells "like a barbecue that's gone wrong", while Italian astronaut Samantha Cristoforetti mentioned a "peculiar odour" she had to adjust to.

Any odour can't be too bad, because of the ISS's atmospheric quality control: module air is circulated by fans through a filtration system that includes activated charcoal beds (like Odor-Eaters in shoes) to remove unwanted chemicals and noxious smells. The ISS interior has weathered better than Russia's Mir space station. That reportedly mildew-scented station became notorious for mould and fungi in the latter part of its 15-year lifetime. Water-repelling coatings were added to ISS interiors to help stave off this problem.

▲ **Cosmonaut Sergey Prokopyev exercises inside the Zvezda module. Fitness became especially important after the leak in the Soyuz module meant crew were stuck on the ISS for over a year**

Maintenance team. "Columbus is situated on the forward 'ram' side of the ISS as it orbits, making it especially vulnerable to debris. Its primary structure is supplemented by a secondary protective structure, the Micrometeoroid/Space Debris Protection System, consisting of single- and double-bumper panels. In practice, however, we have encountered no structural issues whatsoever."

The same is true of the other US and Japanese modules, but in September 2019 Russia's Zvezda service module started leaking. Some ISS air loss is normal through dockings, spacewalks and ongoing purging of waste gases. The statistical standard is 0.27kg of lost air per day, but suddenly this loss doubled, and a year later increased to 1.3kg daily.

By systematically sealing hatches between sections, the loss was traced to the Zvezda module. Loose tea leaves were set floating to pinpoint the leak. These drifted towards the transfer tunnel connecting to the rear docking port. Three hairline cracks were identified here – the largest being 22mm across – then sealed. Some elevated air loss continued however, so that the transfer tunnel is now sealed during normal operations. According to a NASA Inspector General report, the leaks are less likely to have been created by micrometeorite damage than everyday metal fatigue, first encountered in terrestrial air travel, where structural stresses trigger micro-fractures.

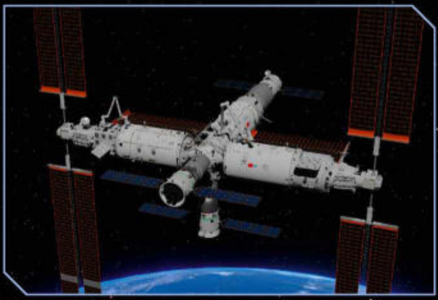
Showing its age

NASA's structural life assessment models failed to forecast this location as risky, raising concerns about other modules – although NASA modules have been safety certified until 2028 and Roscosmos's until 2024. Since then, Russian aerospace firm Energia has identified 'superficial fissures' in the nearly 25-year-old Zarya module as well, although it is unclear whether these are associated with any air loss.

In another age-related effect, the station's original solar arrays are degrading, reducing their power output. In response, a new generation of roller-blind-like solar arrays are being deployed on top of the previous arrays; six out of eight have been installed so far. These operate along with the unshaded elements of the old arrays to generate more electric power than ever – up to a maximum 250 kilowatts, ▶

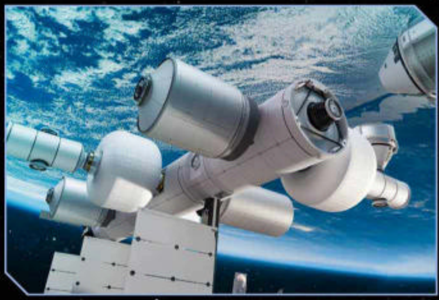
Space stations of the future

Once the ISS is deorbited, human access to low Earth orbit should go on uninterrupted. Various space stations are in development, starting with one already in flight



Tiangong space station (China)
The three-module permanently crewed Tiangong is set to outlive the ISS. A space telescope module will join it next year.
FEASIBILITY: In orbit since April 2021 and planned to last at least a decade, China hopes the station will be a new hub for international cooperation post-ISS.

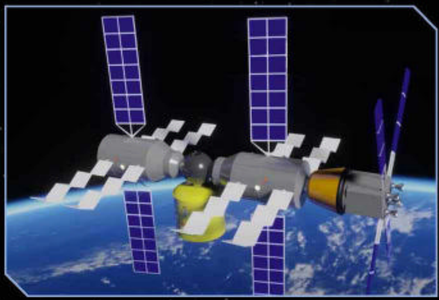
Axiom space station (USA)
This four-module commercial station will be used for in-space manufacturing, experimentation and tourism.
FEASIBILITY: Backed by a NASA Space Act Agreement (SAA), it's due to be built while docked to the ISS. The first two modules have been manufactured.



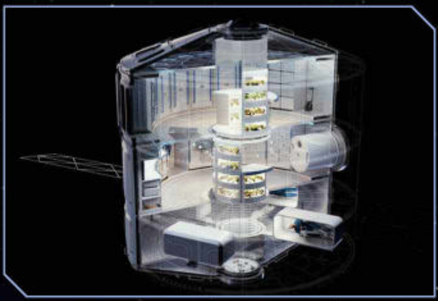
Orbital Reef (USA)
Led by Blue Origin and Sierra Space, this 'business park in space' is based on an expandable primary module.
FEASIBILITY: Backed by a NASA SAA, to be launched by Blue Origin's New Glenn and served by Sierra Space's Dreamchaser spaceplane (both unflown).

Starlab (USA)
Led by Nanoracks, Voyager Space and Lockheed Martin, a commercial station based around an inflatable main module and attached 'science park'.
FEASIBILITY: Backed by a NASA SAA. Nanoracks' Bishop airlock was the first commercial addition to the ISS. Due 2028.

Northrup Grumman station (USA)
A three-module commercial station serving multiple sectors including microgravity research, in-space manufacturing and space tourism.
FEASIBILITY: Backed by a NASA SAA, modules are to be based on the successful Cygnus craft. Stage 1 to launch late 2028.



ISRO Space Station (India)
Intended for 15–20-day stays, this single-module station at 400km will be serviced by crewed Gaganyaan spacecraft.
FEASIBILITY: Russia is providing technical assistance, but Gaganyaan has yet to fly. The space station is planned for the mid 2030s.

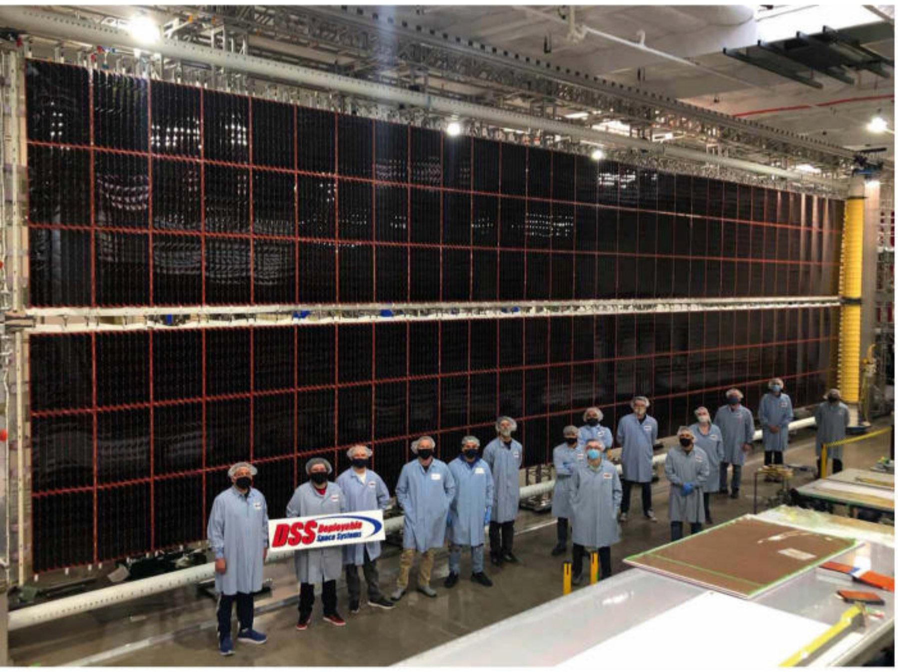


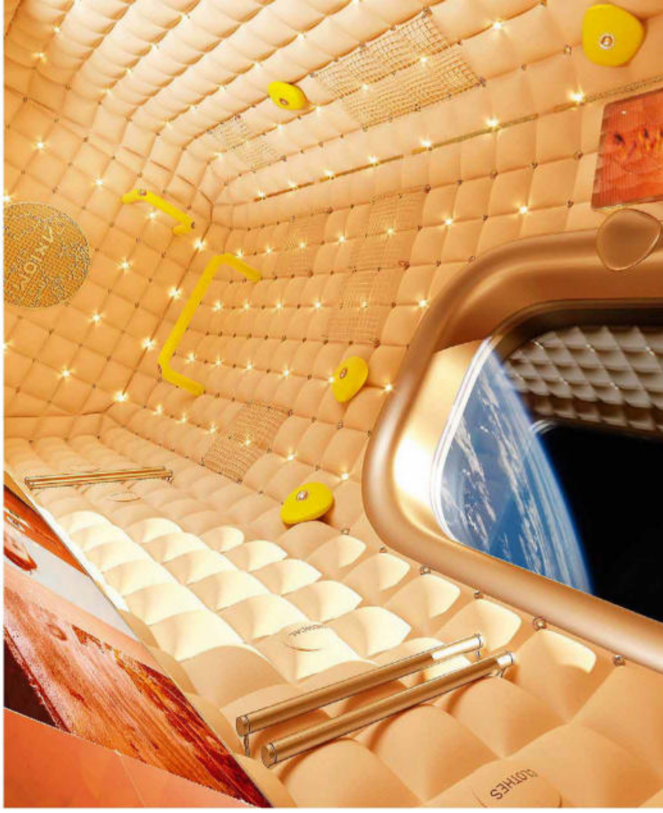
Airbus LOOP (Europe)
An 8m-diameter commercial single-module station with a spacious three-level design for long stays. Suitable for launch by Elon Musk's Starship.
FEASIBILITY: Based on strong European technical heritage, but the project has no customer announced as yet.

Vast space station (USA)
Artificial-gravity habitats for space tourism and manufacturing, to be launched and serviced using SpaceX's Falcon 9 and Crew Dragon. From late 2025.
FEASIBILITY: Backed by financier Jed McCaleb. Artificial gravity will make for a less desirable test environment.

Gateway (USA/Europe/Japan/Canada)
In lunar orbit, this five-module station will serve as a base camp on the way to the Moon's surface.
FEASIBILITY: Needs SLS or Falcon Heavy launches. First module launches late 2025. NASA's Capstone CubeSat is currently trialling Gateway's elliptical orbit.

ALL IMAGES ARE ARTISTS' IMPRESSIONS





▲ The Philippe Starck-designed crew quarters planned for Axiom, the world's first commercial space station

▲ Opportunities are booming for companies like Deployable Space Systems, who upgraded the ISS's solar array, to develop tech for its successors

▶ a 30 per cent increase. This is stored in upgraded lithium-ion batteries for use whenever the station passes out of sunlight.

The ISS's next addition will actually outlive it: the US-based Axiom Space company is due to dock four new modules to the station, starting in 2026 with the launch of Hab One. These combined modules will be tested out during the ISS's remaining years, then separated to become an independent free-floating commercial station. Axiom's is one of several private-sector stations supported through NASA Space Act Agreements (see Space stations of the future, left). Just as the US agency has pivoted to private sector crewed launches, the aim is to commercialise low Earth orbit as a destination, with NASA one customer among many.

Next-generation stations

If all goes to plan, continuous human occupation in space will extend well beyond the life of the ISS (and China's Tiangong station). Staffed by NASA veterans, Axiom has already undertaken the first entirely private ISS mission, while two station modules are completing construction at Thales Alenia Space in Turin – a world leader, having built multiple ISS modules, as well as the pressure shell of the ISS-supplying Cygnus transporter.

The company is also building Europe's contributions to the lunar Gateway, spiritual successor to the ISS, involving all ISS partners apart from Russia. Just one-sixth the size of the ISS, made up of compact modules, this station will operate in elliptical orbit around the Moon's south pole. Four astronauts will stay there for up to 30 days per visit, a limit imposed by the necessity to bring their own air and water aboard their Orion spacecraft.

Gateway might be smaller, but it will also be stronger, says ESA's Materials and Processes Engineer João Gandra: "The Gateway pressure shells, along with those of Axiom and the latest Cygnus versions, are much the same as their ISS predecessors, made from a standard aluminium–copper alloy. The big difference is that they are now welded using 'friction stir welding', a UK-devised technique which softens rather than melts metals, applying friction to join them. This results in stronger welds with improved performance."

Gateway will also be smarter. Unoccupied for much of any given year, it will operate more like a satellite than the current ISS, with a high level of onboard autonomy. The kind of maintenance performed on ISS spacewalks will be undertaken by the Gateway's own robotic arm. The first two modules are due to launch in late 2025, but the station won't even have an airlock until this decade's end.

The future will see not one space station but many. Commercialisation means that various stations may evolve their own specialist niches. The comparatively spacious, luxurious ISS may well be imparted with retrospective glamour. It will symbolise a vanished era when a large part of the world managed to work together as one. We'll miss the ISS when it's gone.

Sean Blair is Senior Editor for European Space Agency Technology and Navigation at EJR-Quartz

▲ Future space-dwellers may look back nostalgically on the spirit of international cooperation behind the ISS

CNSA, AXIOM SPACE/INCX 2, BLUE ORIGIN/LLC, VOYAGER SPACE HOLDINGS 2023, NORTHRUP GRUMMAN, ISRO, ESA, AIRBOS, DEPLOYABLE SPACE SYSTEMS, VAST SPACE LLC, NASA

BBC Sky at Night MAGAZINE

The Sky Guide

NOVEMBER 2023

MIGHTY JUPITER

The magnificent planet is in a prime position for its opposition on 3 November

VENUS VANISHES

See the planet occulted by the Moon in daylight

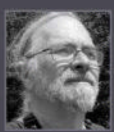
PETE LAWRENCE

DRAMA QUEEN

Stunning deep-sky sights to hunt near Cassiopeia

About the writers

Astronomy expert **Pete Lawrence** is a skilled astro imager and a presenter on *The Sky at Night* monthly on BBC Four



Steve Tonkin is a binocular observer. Find his tour of the best sights for both eyes on page 54

Also on view this month...

- ✦ Asteroid 18 Melpomene at opposition
- ✦ Jupiter moon events
- ✦ Binocular targets around Cetus
- ✦ Uranus at opposition

Red light friendly

To preserve your night vision, this Sky Guide can be read using a red light under dark skies

Get the Sky Guide weekly

For weekly updates on what to look out for in the night sky and more, sign up to our newsletter at **www.skyatnightmagazine.com**

NOVEMBER HIGHLIGHTS

Your guide to the night sky this month

Friday 3

Jupiter reaches opposition when it can be seen shining at an impressive mag. –2.8 in southern Aries.

Saturday 4

Rising just after 22:00 UT, the 53%-lit waning gibbous Moon sits 3° north of the Beehive Cluster, M44.

Europa transits in sync with its shadow, from 01:16 until 03:35 UT.

Sunday 5

Io transits in sync with its shadow between 03:55 and 06:07 UT.

Wednesday 8

Another Io transit this evening, the moon now well ahead of its shadow. The event starts at 16:45 UT and concludes at 19:00 UT.

Thursday 9 ▶

A daylight lunar occultation of Venus. The event occurs between 09:43 and 10:41 UT from the UK's centre, varying slightly with location. Venus has a 58% phase, appearing 20 arcseconds across.

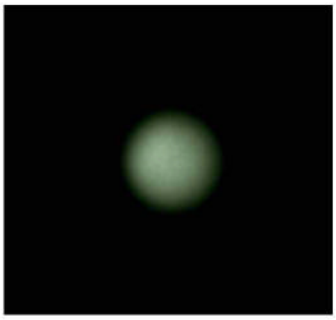
Saturday 11

Jupiter's Great Red Spot is beautifully presented early evening, appearing on the planet's centre line at 20:45 UT.

Sunday 12

The Moon is completely out of the way at present, leaving the skies good and dark. It's a perfect time to try our Deep-Sky Tour on page 56.

Northern Taurid meteor shower peak (ZHR 5).



◀ Monday 13

Uranus reaches opposition when it can be seen shining at mag. +5.6 amongst the stars of Aries.

Saturday 18 ▶

The Leonid meteor shower reaches its peak, with maximum activity expected this morning under favourable conditions (ZHR 15).

Monday 20

The first quarter Moon this evening sits 3.6° south-southeast of mag. +0.7 Saturn.

Family stargazing

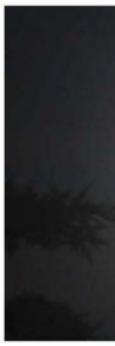
Using a small telescope, try to spot some of the Jupiter moon and shadow transits listed in this month's calendar. It's easier to see one of Jupiter's brighter moons before a transit starts, when it's away from the planet. As it passes in front of Jupiter, it can become lost from view, but its shadow should be visible as a tiny dark spot. Different moons show different sizes of shadow. If the weather is kind, grab a view of the Ganymede transit in the early evening on 10 November. Being the largest moon in the Solar System, Ganymede's shadow is huge! **www.bbc.co.uk/cbeebies/shows/stargazing**

Friday 24

Ganymede and its shadow transit Jupiter's southern polar region between 23:58 UT tonight and 03:50 UT on 25 November.

Saturday 25 ▶

This evening the almost full Moon is located close to mag. –2.7 Jupiter.



PETE LAWRENCE X 8

Monday ▶

6 After opposition on 3 November, this evening Io appears to transit Jupiter from 22:21 UT, just ahead of its shadow.

Friday ▶

10 Ganymede and its shadow put on a lovely transit between 17:30 and 19:45 UT.

Libration favours a view of the Moon's Mare Orientale this morning.

Tuesday

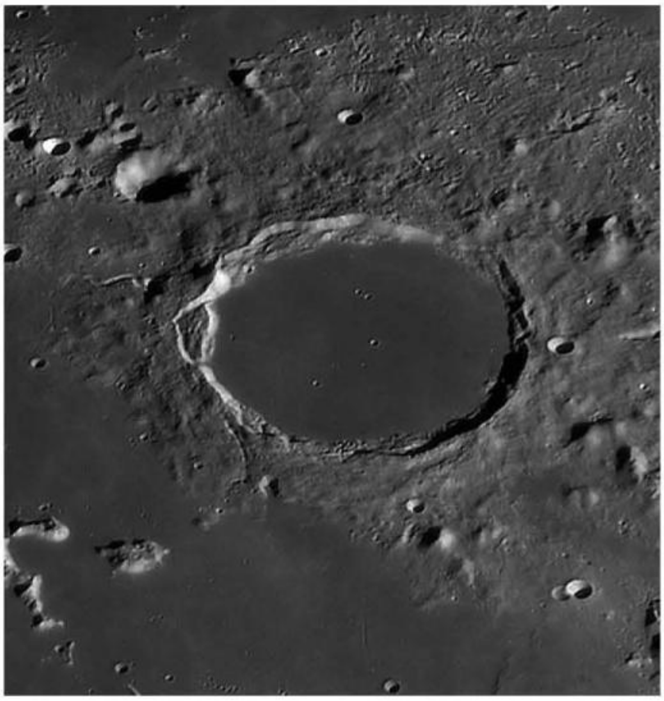
14 Europa and its shadow transit Jupiter between 16:35 and 19:28 UT. Callisto drifts south of Jupiter as this is happening.

Friday

17 Ganymede and its shadow transit Jupiter's southern polar region between 20:43 and 23:45 UT.

Tuesday ▶

21 This month's Moonwatch target (see page 52), the large crater Plato, is nicely presented on this evening's 67%-lit waxing gibbous Moon.



NEED TO KNOW

The terms and symbols used in The Sky Guide

Universal Time (UT) and British Summer Time (BST)
Universal Time (UT) is the standard time used by astronomers around the world. British Summer Time (BST) is one hour ahead of UT

RA (Right ascension) and dec. (declination)
These coordinates are the night sky's equivalent of longitude and latitude, describing where an object is on the celestial 'globe'

Family friendly
Objects marked with this icon are perfect for showing to children

Naked eye
Allow 20 minutes for your eyes to become dark-adapted

Photo opp
Use a CCD, planetary camera or standard DSLR

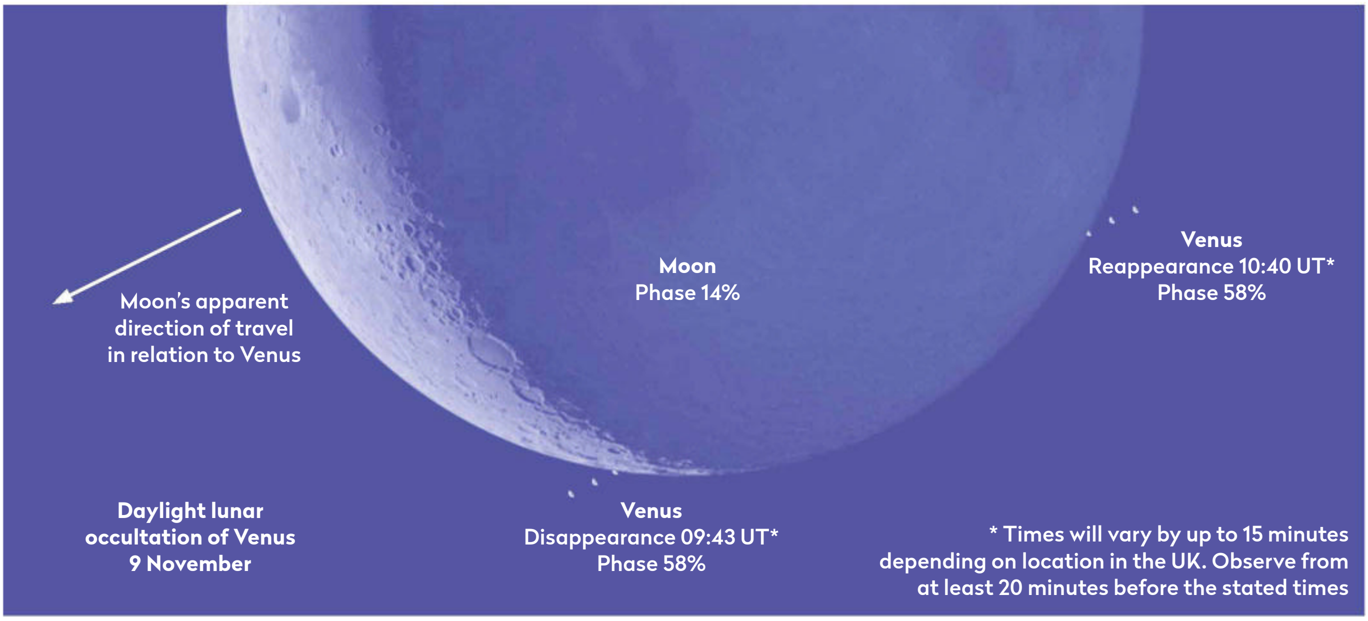
Binoculars
10x50 recommended

Small/ medium scope
Reflector/SCT under 6 inches, refractor under 4 inches

Large scope
Reflector/SCT over 6 inches, refractor over 4 inches

GETTING STARTED IN ASTRONOMY

If you're new to astronomy, you'll find two essential reads on our website. Visit **bit.ly/10_easylessons** for our 10-step guide to getting started and **bit.ly/buy_scope** for advice on choosing a scope



▲ Despite being a daylight event, the occultation of Venus by a crescent Moon on 9 November should be easy to see given clear skies

DON'T MISS

Lunar occultation of Venus

BEST TIME TO SEE: Before sunrise on 9 November, through to 11:00 UT

From the UK, the Moon appears to hide Venus on the morning of 9 November, an event occurring during daylight. Unlike the very tricky daylight lunar occultation (or close pass, depending on your location) of Jupiter back in May of this year, this month's event should be easier to see.

The Moon appears as a 15%-lit waning crescent on 9 November. Venus will be just past dichotomy and showing as a 58%-lit gibbous disc, 20 arcseconds across through the eyepiece. It'll be bright too, shining at mag. –4.2. Given clear skies, Venus will be visible to the naked eye and easy to see through binoculars.

The Moon's separation from the Sun at occultation time will be 46°, a reasonable distance away. However, caution must be exercised when looking for something while the Sun is above the horizon. Ideally, place yourself in the shadow of a building or fence so that the Sun is hidden but the sky to the right of it is visible.

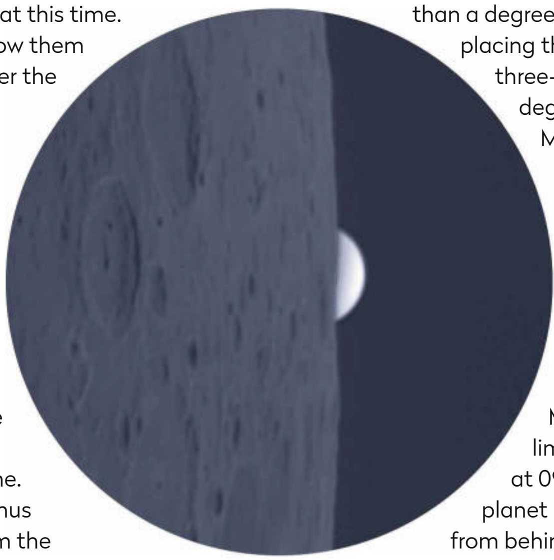
On the morning of 9 November, from the UK's centre, the Moon rises slightly ahead of Venus at 02:38 UT, the planet appearing 15 minutes later, just before 03:00 UT. Both rise above the east point on the horizon, the Moon appearing 2.7° from Venus at this time.

If you can follow them in clear skies, over the course of a few hours the separation between the two reduces to produce an ever more dramatic scene against the dark morning sky, the pair gaining altitude with time. By 05:00 UT, Venus appears 1.8° from the Moon's centre, with both objects sitting at an altitude of around 20°.

By 06:00 UT, the dawn twilight will be under way, but the sky will still be sufficiently dark to provide a dramatic, high-contrast background. Venus will now be 1.4° from the Moon's centre, just over a degree from the edge of the lunar crescent. Their altitude will have increased to nearly 30° by 06:00 UT.

Sunrise occurs just before 07:30 UT, but if you've been following the pair up to this point they should still be easy to see. The separation between Venus and the Moon's centre will be fractionally less than a degree at sunrise, placing the bright planet three-quarters of a degree from the Moon's edge.

Timings for the occultation vary slightly depending upon location. Viewed from the centre of the UK, the Moon's bright limb hides Venus at 09:43 UT, the planet reappearing from behind the dark limb almost an hour later at around 10:39 UT. Those living in the south of the UK get the shortest occultation; those living in the north get the longest.



▲ Venus emerging from behind the Moon's bright limb during an occultation on 18 June 2007. The brightness difference between Venus and the lit portion of the Moon is striking

ALL PICTURES: PETE LAWRENCE

Jupiter moon events

BEST TIME TO SEE: As stated

Jupiter reaches opposition on 3 November and is becoming well-positioned at present, reaching 50° altitude from the centre of the UK, when it lies dues south. Opposition also provides an excellent opportunity to witness some of the beautiful interactions which can occur between the planet and its four brightest 'Galilean' moons, Io, Europa, Ganymede and Callisto.

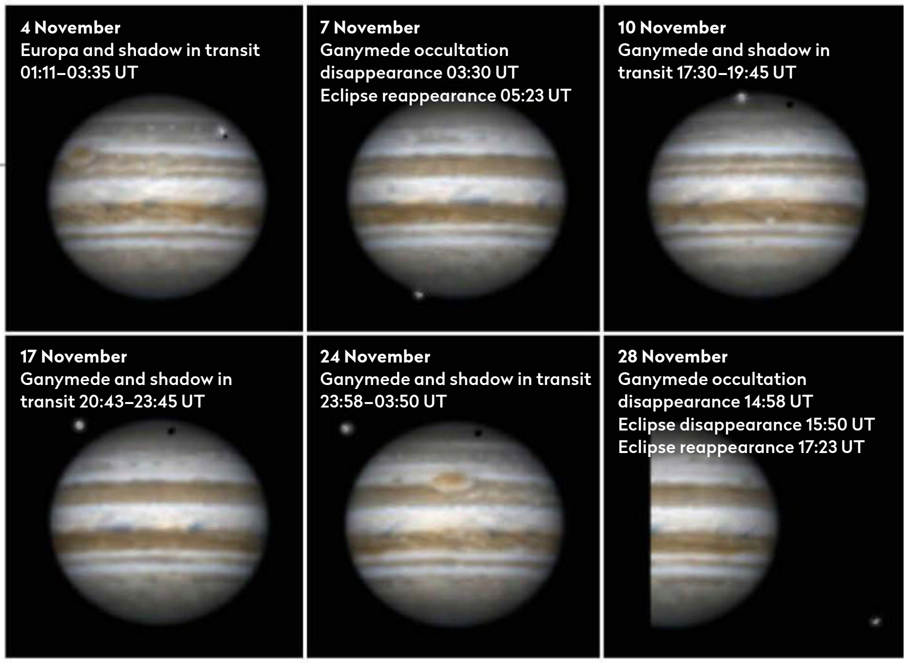
On 4 November between 01:16 and 03:35 UT, Europa is chased by its shadow. Just after opposition, moon and shadow appear to almost touch. On 5 November between 03:55 and 06:07 UT and on 6/7 November between 22:21 and 00:36 UT it's the turn of Io to be chased by an almost touching shadow.

On the morning of 7 November between 03:30 and 05:23 UT, Ganymede is occulted by Jupiter, followed by its reappearance from the planet's shadow some distance away (an eclipse reappearance). On the 10th, Ganymede and its shadow appear to pass in front of Jupiter between 17:30 and 19:45 UT.

Ganymede experiences another occultation disappearance on 14 November at 06:43 UT, but doesn't reappear before Jupiter sets. Later, Callisto can be seen south of Jupiter as darkness falls. Also on that evening, Europa and its shadow transit at 16:35–19:28 UT, Io experiencing an occultation disappearance at 21:20 UT, reappearing from Jupiter's shadow at 23:47 UT.

There are two further transits by Ganymede and its shadow: on 17 November at 20:43–23:45 UT and on 24/25 November at 23:58–03:50 UT. Finally, on 28 November Ganymede reappears from eclipse at 17:23 UT, Europa and its shadow are in transit from 21:05 until 00:39 UT, and Io is occulted by Jupiter at 00:49 UT, reappearing from the planet's shadow at 03:37 UT.

These are just a selection of the Jovian moon events this month, so you should have a chance to catch some of them.



▲ Some of the Jovian moon events you can see this month (south is up)

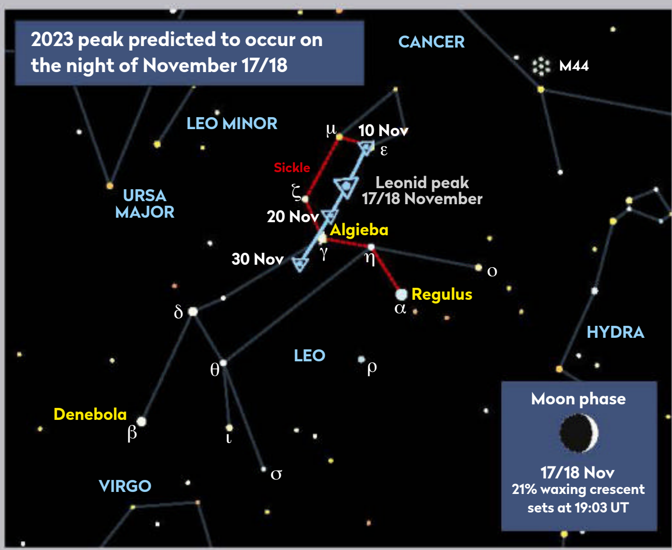
Leonids 2023

BEST TIME TO SEE: 6–30 November, best views midnight on 17 November until dawn on 18 November

November plays host to the Leonid meteor shower. Active between 6–30 November, the shower reaches peak activity on the night of 17/18 November. The Leonids are associated with comet 55P/Tempel–Tuttle and at their peak are expected to produce a Zenthal Hourly Rate (ZHR) of 15 meteors per hour. This is under ideal conditions though, so expect to see less.

The significant factors affecting the visibility of a meteor display are light pollution, weather, the Moon and radiant altitude. On the evening of 17 November, the Moon appears as a 21%-lit waxing crescent. Low above the southern horizon at sunset, this early-phase crescent sets around 19:00 UT, leaving the rest of the night good and dark for meteor watching.

The Leonid radiant is located within the head of Leo, depicted by the Sickle asterism. The radiant itself rises around 22:20 UT, attaining a peak altitude of nearly 60° around 05:40 UT. After this time, astronomical dawn will be in force with the sky slowly brightening to bring the observing window to a close. The best time to watch for Leonids will be after the radiant has gained some height, say from midnight on 17 November through to dawn on the 18th.



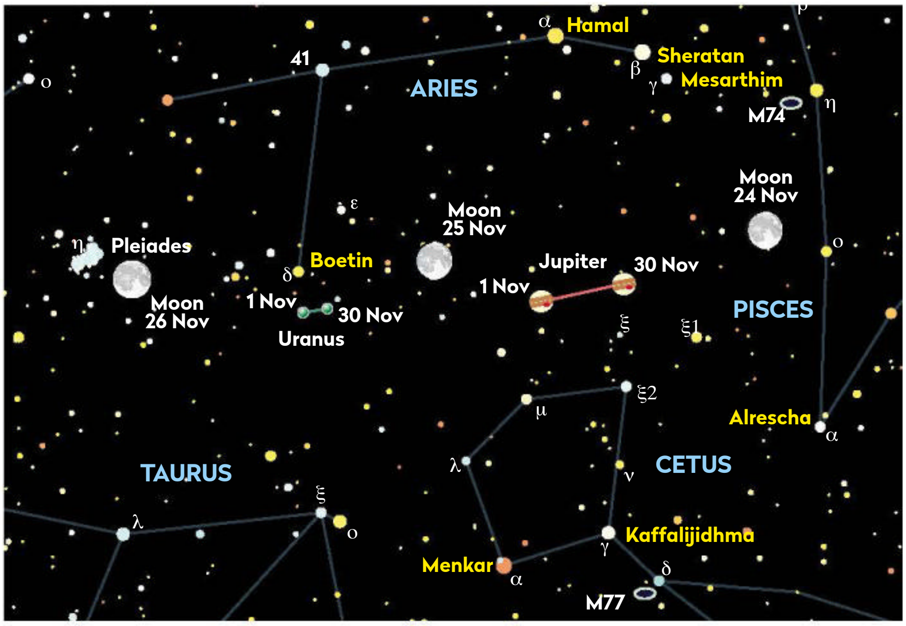
▲ The Leonid meteor shower peak is favourable in 2023, the Moon not interfering. It has a predicted ZHR of 15 meteors an hour

THE PLANETS Our celestial neighbourhood in November

PICK OF THE MONTH

Jupiter

Best time to see: 3 November, from 00:00 UT
Altitude: 51°
Location: Aries
Direction: South
Features: Complex atmosphere, Galilean moons
Recommended equipment: 75mm or larger

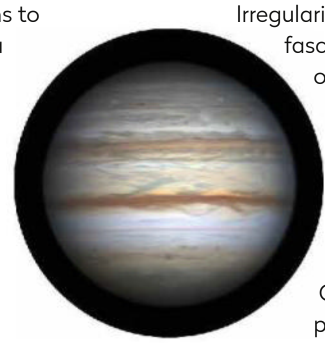


▲ Jupiter is currently near Uranus, both well-placed planets for observation from the UK

Magnificent Jupiter reaches opposition on 3 November and is currently a dominant night-time planet. Shining at mag. –2.8 at the start of the month, it dims only marginally to –2.7 by the end of November. It reaches a peak altitude of around 50° when due south and manages this under dark-sky conditions all month. This puts it in an extremely favourable place for observing through the eyepiece or imaging with a camera, as the planet will be above the turbulent atmosphere found closer to the horizon. A bright, almost full Moon (also at opposition) sits near Jupiter on the evenings of 24 and 25 November.

Jupiter has much to offer through small and large telescopes. A small scope will show its oblate nature, a consequence of it being a large gaseous body which rotates once in just under 10 hours. This causes its equatorial regions to bulge outward. It also has a complex atmosphere, a 100mm scope showing the two main bands and, under good conditions, the Great Red Spot. Its four brightest moons are easy to spot through any size of telescope.

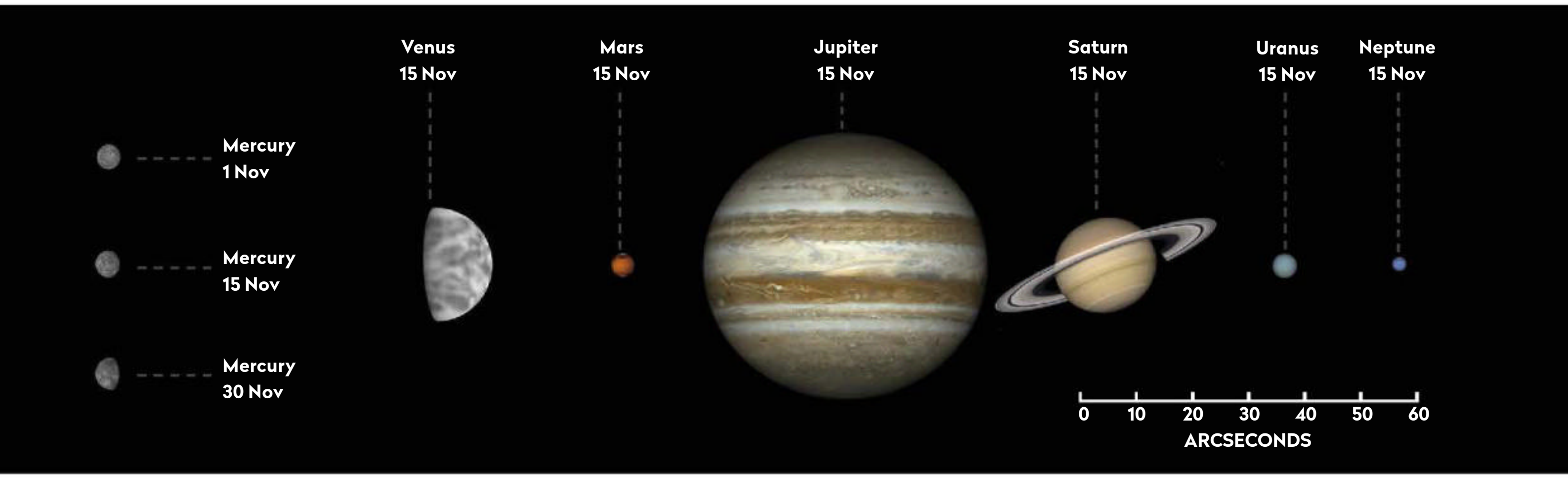
Larger scopes will reveal greater detail in Jupiter's atmosphere. The Great Red Spot becomes a lot easier to see with bigger aperture, along with more of the minor bands and zones. Irregularities in the atmosphere are fascinating to record and track over time. Applications such as the freeware WinJupos (**jupos.org/gh/download.htm**) can be used for image measurement, as well as providing timings for the visibility of the Great Red Spot and the positions of the planet's four Galilean moons. WinJupos also has many useful tools to assist with image processing.


▲ Jupiter's complex atmosphere as it appeared in 2022

PETE LAWRENCE X 2

The planets in November

The phase and relative sizes of the planets this month. Each planet is shown with south at the top, to show its orientation through a telescope



Mercury

Best time to see: 30 November, 40 minutes after sunset
Altitude: 1° (extremely low)
Location: Sagittarius
Direction: Southwest
Mercury is an evening planet but despite being brightest at the start of the month, it is poorly positioned during November and sets relatively soon after the Sun. On 21 November, for example, shining at mag. −0.4 and separated from the Sun by nearly 18°, Mercury sets less than 40 minutes after sunset. This does increase to around 1 hour by the end of November and the planet manages to maintain a similar brightness throughout this period.

Venus

Best time to see: 1 November, from 05:00 UT
Altitude: 21°
Location: Leo
Direction: East-southeast
Venus is a morning object visible against astronomically dark skies for a good length of time throughout November. On 1 November, the planet shows as a 54%-lit gibbous disc through the eyepiece and appears 22 arcseconds across. It shines at mag. −4.2 on this date, rising nearly 4.5 hours before the Sun. On 30 November, its phase will have increased to 67% and its apparent diameter reduced to 17 arcseconds. On the 30th, mag. −4.1 Venus will rise 4.2 hours before the Sun. The waning crescent Moon occults Venus during the morning of 9 November. Turn to page 46 for further details.

Mars

Not visible this month
Not a viable target as it's too close to the Sun in the evening sky. Solar conjunction is on 17 November, after which Mars becomes a morning object.

Saturn

Best time to see: 1 November, 19:40 UT
Altitude: 24°
Location: Aquarius
Direction: South
Saturn is a mag. +0.8 evening planet during November, able to reach its highest position, due south, under fairly dark-sky conditions all month. Currently in Aquarius, not far from mag. +4.3 Iota (ι) Aquarii, the planet manages to reach an altitude around 24° up when due south as seen from the centre of the UK. The first quarter Moon sits 3.5° southeast of Saturn on the evening of 20 November.

Uranus

Best time to see: 13 November, 23:55 UT
Altitude: 55°
Location: Aries
Direction: South
Uranus is presented optimally this month, the planet reaching opposition on 13 November when it can be found near the Aries–Taurus border, shining at mag. +5.6. Look for it 2.2° south of mag. +4.3 Botein (Delta (δ) Arietis).

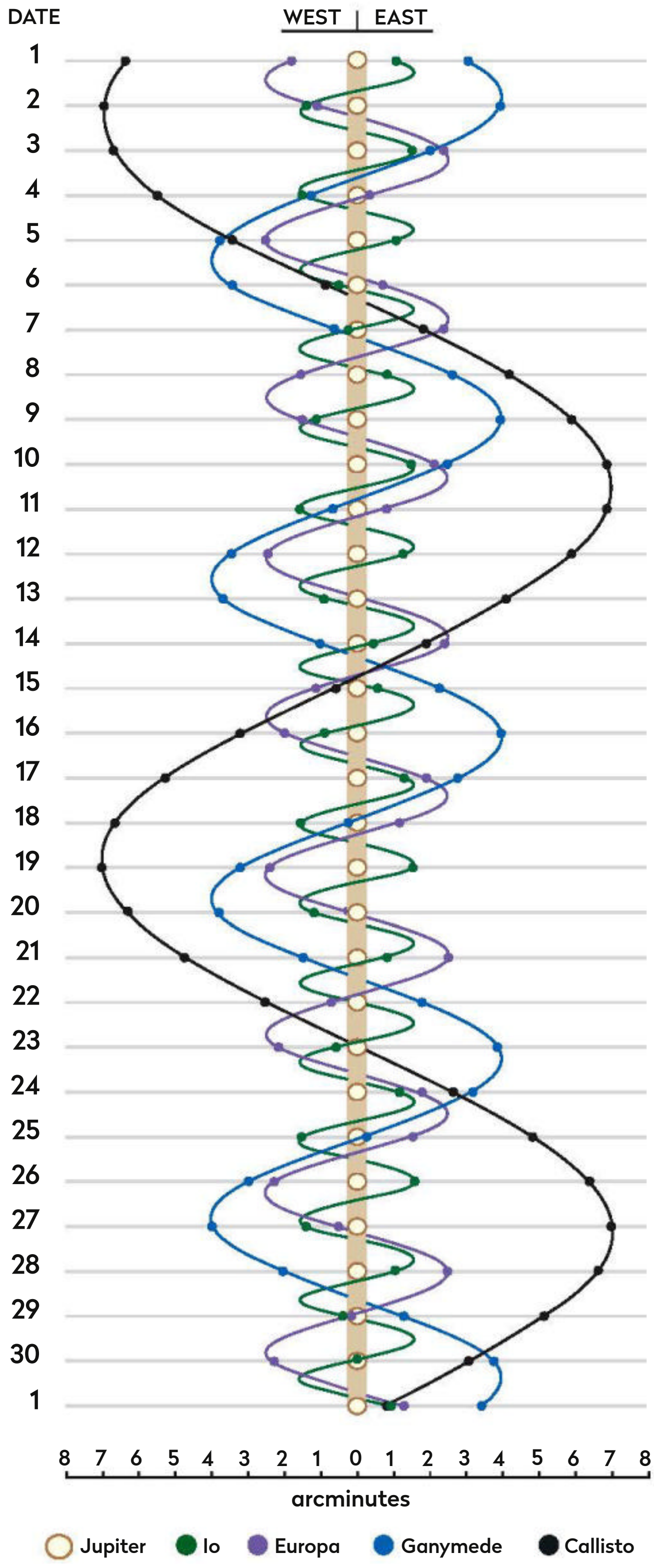
Neptune

Best time to see: 1 November, 21:13 UT
Altitude: 34°
Location: Pisces
Direction: South
Neptune is an evening planet, favourably placed all month. It's able to reach a peak altitude of 34° under dark-sky conditions throughout November. Shining at mag. +7.9, a minimum of binoculars is required to see it.

MORE **ONLINE**
Print out observing forms for recording planetary events

JUPITER'S MOONS: NOVEMBER

Using a small scope you can spot Jupiter's biggest moons. Their positions change dramatically over the month, as shown on the diagram. The line by each date represents 00:00 UT.



THE NIGHT SKY – NOVEMBER

Explore the celestial sphere with our Northern Hemisphere all-sky chart

KEY TO STAR CHARTS

- Arcturus — STAR NAME
- PERSEUS — CONSTELLATION NAME
- GALAXY
- OPEN CLUSTER
- GLOBULAR CLUSTER
- PLANETARY NEBULA
- DIFFUSE NEBULOSITY
- DOUBLE STAR
- VARIABLE STAR
- THE MOON, SHOWING PHASE
- COMET TRACK
- ASTEROID TRACK
- STAR-HOPPING PATH
- METEOR RADIANT
- Circlet — ASTERISM
- PLANET
- QUASAR

STAR BRIGHTNESS:

- MAG. 0 & BRIGHTER
- MAG. +1
- MAG. +2
- MAG. +3
- MAG. +4 & FAINTER

- COMPASS AND FIELD OF VIEW (N, E, S, W, 5°)
- MILKY WAY

CHART: PETE LAWRENCE

When to use this chart

1 November at 00:00 UT
15 November at 23:00 UT
30 November at 22:00 UT

On other dates, stars will be in slightly different positions because of Earth's orbital motion. Stars that cross the sky will set in the west four minutes earlier each night.

How to use this chart

1. Hold the chart so the direction you're facing is at the bottom.
2. The lower half of the chart shows the sky ahead of you.
3. The centre of the chart is the point directly over your head.

Sunrise/sunset in November*

Date	Sunrise	Sunset
1 Nov 2023	07:08 UT	16:38 UT
11 Nov 2023	07:27 UT	16:20 UT
21 Nov 2023	07:46 UT	16:05 UT
1 Dec 2023	08:02 UT	15:55 UT

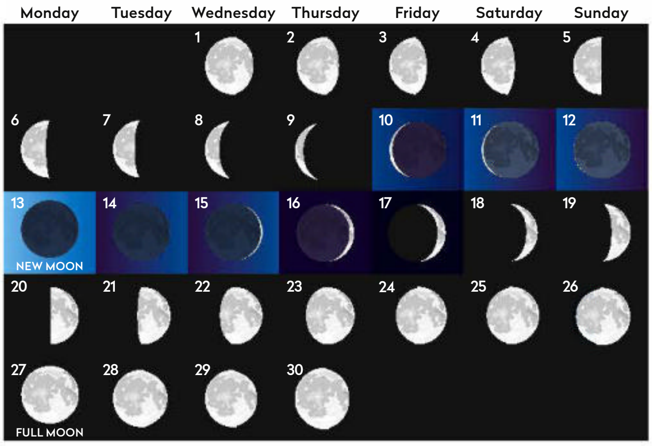
Moonrise in November*

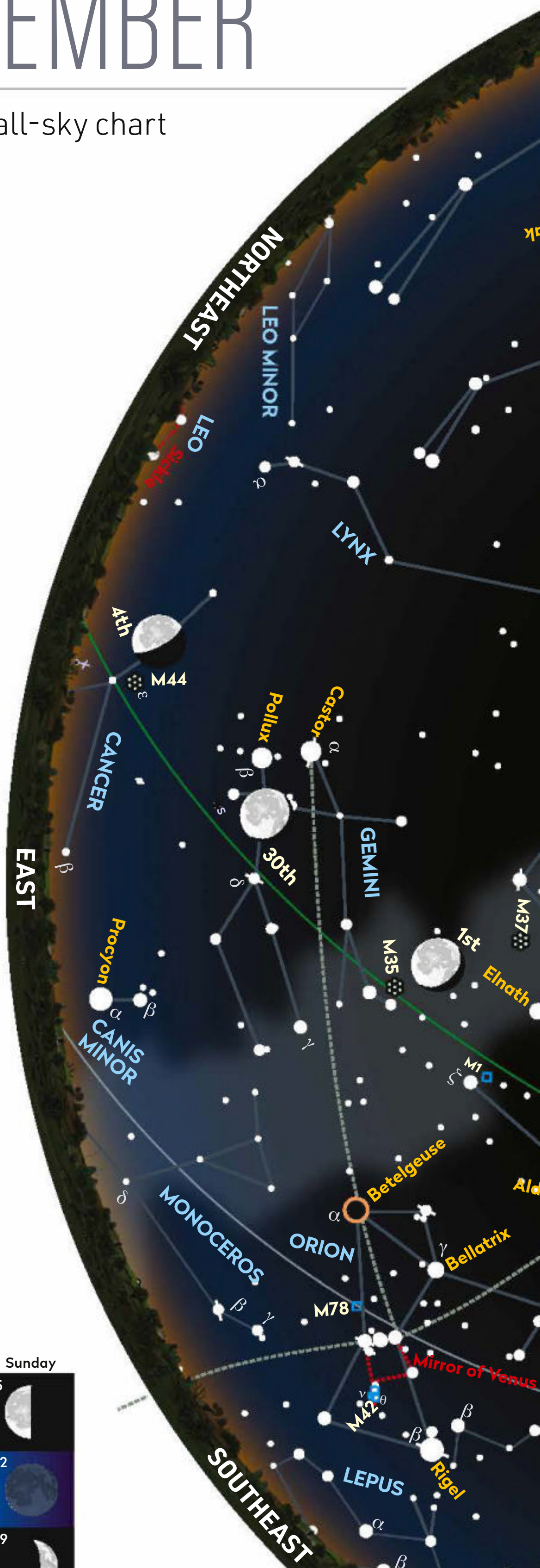
Moonrise times

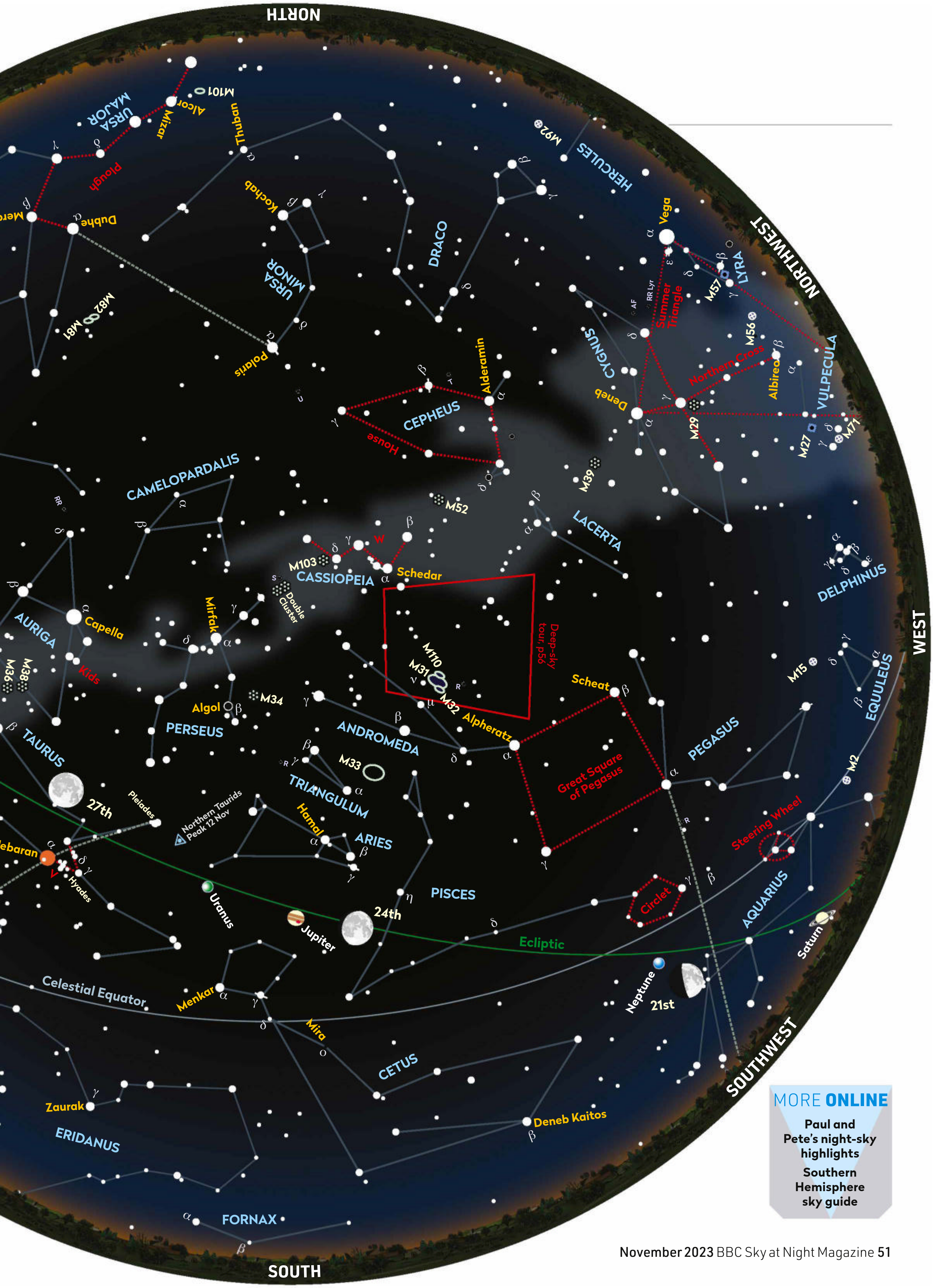
1 Nov 2023, 18:16 UT	17 Nov 2023, 12:40 UT
5 Nov 2023, 22:53 UT	21 Nov 2023, 14:08 UT
9 Nov 2023, 02:38 UT	25 Nov 2023, 14:52 UT
13 Nov 2023, 07:46 UT	29 Nov 2023, 16:57 UT

*Times correct for the centre of the UK

Lunar phases in November







MORE ONLINE

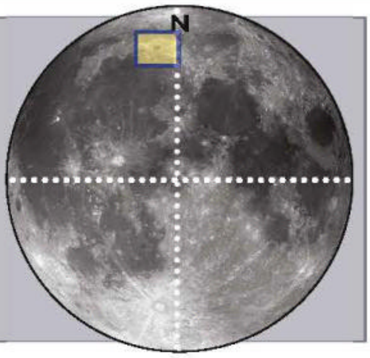
Paul and Pete's night-sky highlights

Southern Hemisphere sky guide

MOONWATCH November's top lunar feature to observe

Plato

Type: Crater
Size: 101km
Longitude/latitude: 9.4° W, 51.6° N
Age: 3.2–3.8 billion years
Best time to see: 1 day after first quarter (20 and 21 November) or last quarter (5 and 6 November)
Minimum equipment: 10x binoculars



Plato is a large, circular crater on the northern border of the immense 1,250km Mare Imbrium. It's one of the defining features on the Earth-facing side of the Moon's globe. Its smooth dark floor framed with a complete elevated rim is very distinctive.

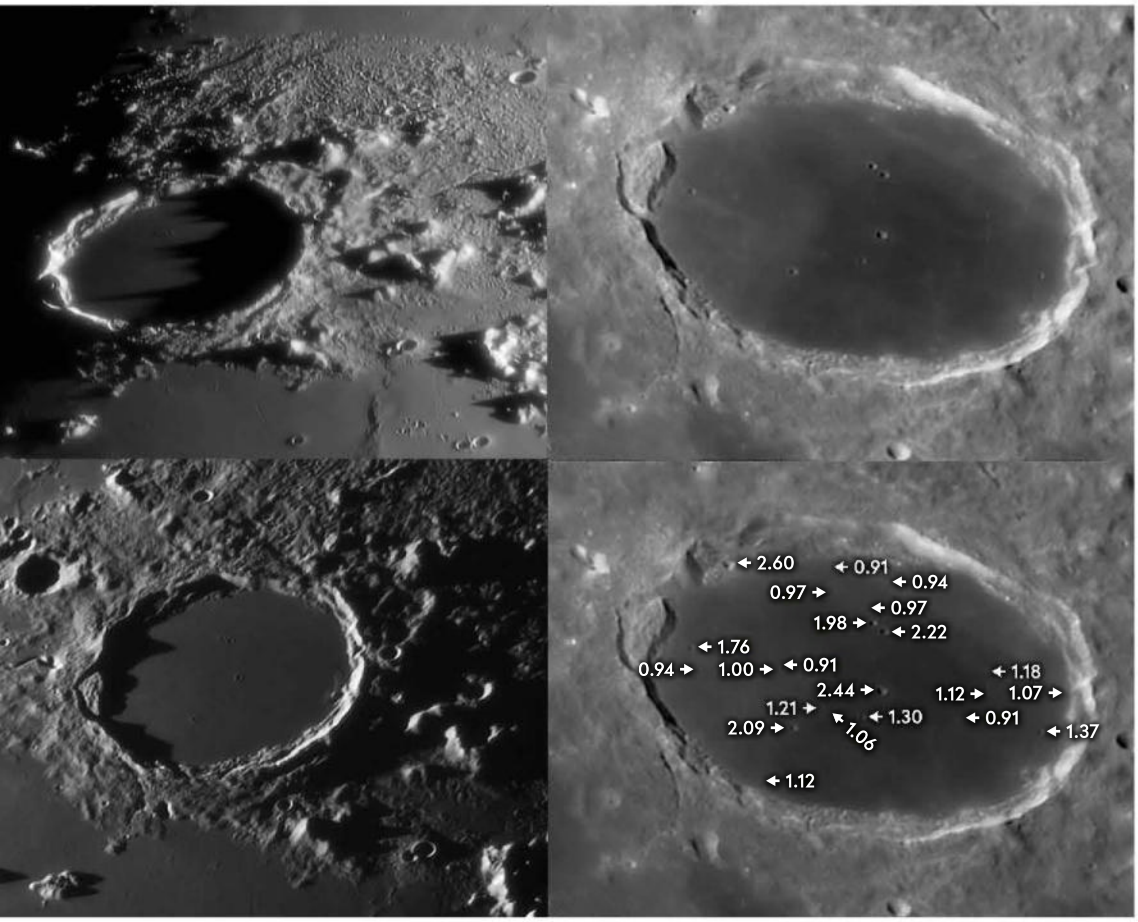
On average, Plato's rim towers 1.7km above the crater's floor with several peaks rising significantly above this height. On the western rim sits what used to be called Plato Zeta, the peak which casts the longest shadow when sunset falls on Plato. **Zeta** rises to a height around 2.9km above floor level. The eastern rim has three prominent peaks originally referred to as **Plato Gamma**, **Delta** and **Epsilon** (south to north). These cast jagged shadows across Plato's floor at sunrise and rise to heights of 3.2km, 2.6km and 1.9km respectively. There are two additional peaks between Gamma and Delta which are both slightly higher than Epsilon.

Plato seems pretty straightforward – an elevated ring with a smooth, flat floor. However, it's a crater with numerous oddities. A report by British amateur astronomer WR Birt around 1871 suggested that Plato changed colour when the Sun rose above the crater. Originally believed to be due to the ebb and flow of lunar vegetation, modern photometry has shown that there is no variation and the effect was illusory. As the Sun rises, its floor, like the surface of **Mare Imbrium** to the south, brightens at a slower rate than the more reflective highland areas east, west and north of Plato. Increased contrast then makes Plato look darker.

Plato's rim looks intact at first glance, but some of the western section has detached and dropped. The highest western rim peak is just north of this section. A quick look at Plato's floor suggests it's smooth. However, different illuminations show a plethora of tiny craterlets scattered across the floor which serve as excellent tests for telescope optics, imaging resolution and seeing conditions. The largest, near Plato's centre, is just 2.44km across. If you can't see these very well, persevere because their appearance changes under different phases and seeing conditions.

A more peculiar phenomenon occurs after sunrise. A sharp shadow produced by the 'Gamma' peak was reported by Wilkins and Moore on 3 April 1952 to look curved. Now known as **Plato's Hook**, the cause of the curved shadow remains controversial even today. Was it due to the shadow falling on a bulged section of floor, or perhaps an illusion due to its proximity to the rough debris hills near the crater's southern rim? The only way to tell is to observe the shadow's formation in detail, something that phase timing and weather makes quite tricky. If you want to give it a go, the co-longitude value for the hook is 15.6°, a value which next occurs on 21 November just before 16:00 UT. Co-longitude values can be determined using freeware such as WinJupos (**jupos.org/gh/download.htm**) or the Virtual Lunar Atlas (**ap-i.net/avl/en/start**).

PETE LAWRENCE X 3



▼ **Clockwise from bottom left: lighting effects on Plato at sunset; and at sunrise; its fully-lit, craterlet-littered floor; internal craterlet diameters marked in kilometres**

COMETS AND ASTEROIDS

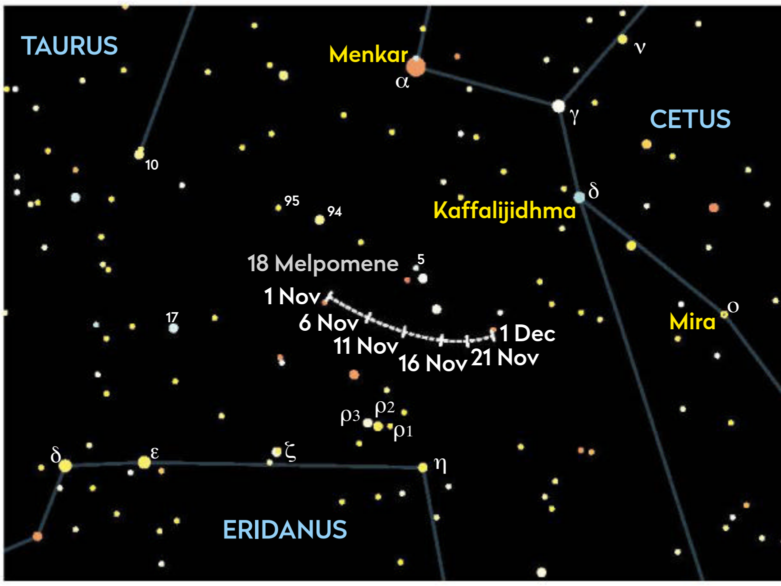
Large, bright main-belt asteroid Melpomene is a binocular possibility

Minor planet 18 Melpomene reaches opposition on 5 November when it can be found in the northwest corner of Eridanus, the River, shining at mag. +8.2. At this brightness, it's within binocular range and as it doesn't move an enormous distance throughout the month, it should be relatively easy to keep tabs on.

Melpomene is a large main-belt asteroid that fits within a tri-axial ellipsoid measuring 170 x 155 x 129km. Its orbit brings it as close as 268.5 million km (1.8 AU) from the Sun at perihelion and out as far as 418.4 million km (2.8 AU) at aphelion. It takes 1,270.6 days (3.5 years) to complete each orbit. Melpomene is an S-type, silicaceous asteroid with a stony composition. It's relatively bright and varies in magnitude between +7.5 at favourable oppositions and +12.0 at unfavourable ones. During 2023 it's closer to the favourable end of this range, starting the month at mag. +8.2, maintaining +8.2 at opposition and ending it at mag. +8.7.

It was discovered by English astronomer John Russell Hind on 24 June 1852 and, following the occultation of a star on 11 December 1978, was believed to have its own moon. Follow-up observations by the Hubble Space Telescope in 1993 revealed the asteroid's elongated shape, but failed to detect the suspected moon. Thus is seems Melpomene is alone.

Locating Melpomene from Eridanus will be a tricky task as the constellation is long, sprawling and mostly faint. If you do try, Melpomene's short November track describes a south-pointing arc between the three stars Rho^1 (ρ^1), Rho^2 (ρ^2) and Rho^3 (ρ^3) Eridani and 5 Eridani. An easier method of location may be, at the start of November, to extend the line from Lambda (λ) Ceti and Menkar (Alpha (α) Ceti) for 1.4 times.



▲ Melpomene's track below the head of Cetus in November

STAR OF THE MONTH

Navi, the middle of the unmistakable 'W' of Cassiopeia

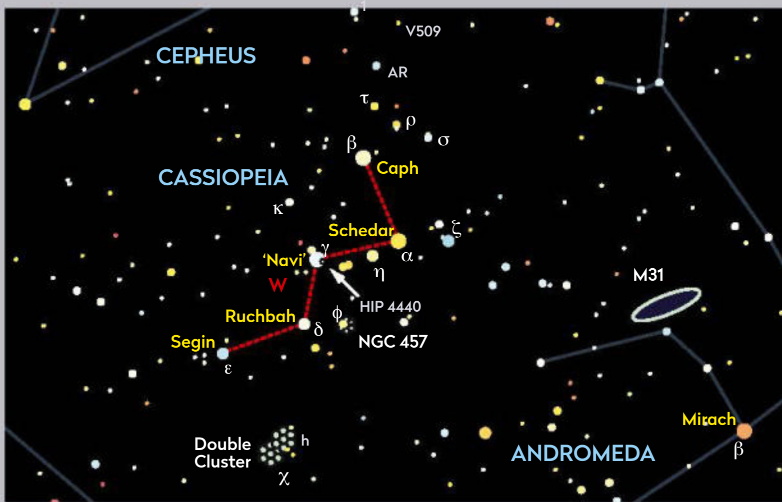
Cassiopeia is an easily identifiable circumpolar (never sets) constellation for UK viewers. The central star is Gamma (γ) Cassiopeiae, sometimes known by the unofficial name 'Navi', a name given to it by the American astronaut Virgil 'Gus' Grissom, first because it's an easy to spot 'navi'gational star and second because it's Grissom's middle name, Ivan, spelled backwards.

Listed as mag. +2.5, it's an eruptive variable, its brightness varying between mag. +1.6 and +3.0 at irregular intervals. It's fairly distant at 560 lightyears and was once thought to be a rare example of an octonary system, eight gravitationally bound stars.

It's a rapid rotator at 472km/s, which means it'll be bulging noticeably at its equator. A hot circumstellar gaseous disc is believed to have formed around the star and this is probably the source of its brightness variations. Navi's spectral type is B0.5 IVe: a blue-white subgiant with hydrogen emission lines in its spectrum, again likely caused by the circumstellar gas disc.

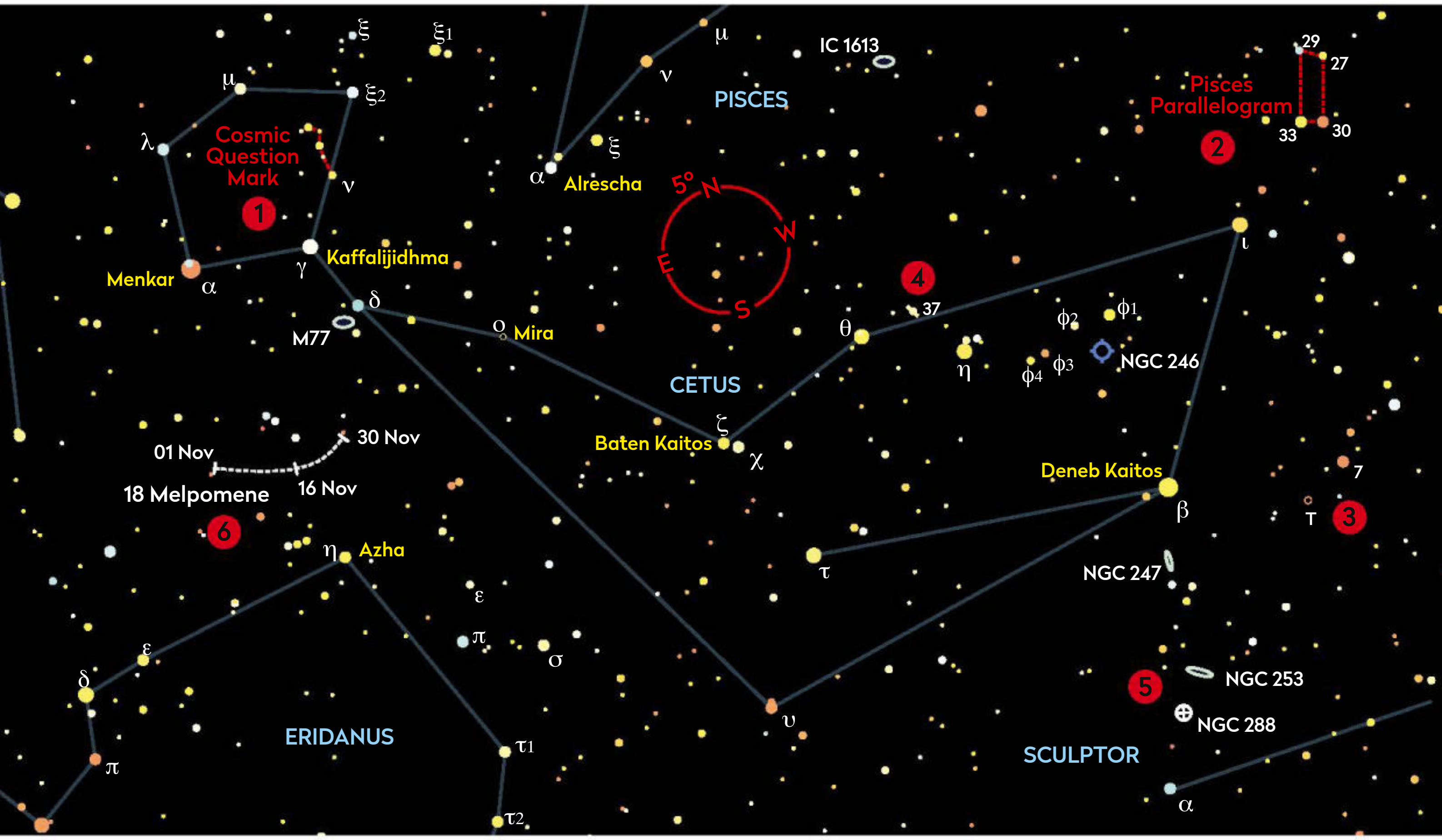
Three companions are listed in double star catalogues. Navi's primary, Gamma Cassiopeiae A, is itself a spectroscopic binary. Two share common proper motion with Navi and are likely physically associated, although one appears more distant. One of these two companions is mag. +5.5 HIP 4440, visible to the naked eye 21 arcminutes south of Navi and known to be a quadruple system.

▼ Astronaut Gus Grissom gave Gamma Cassiopeiae the nickname 'Navi'



BINOCULAR TOUR With Steve Tonkin

Join us for some whale watching as we find widefield sights around Cetus



PETE LAWRENCE X 3

1. The Cosmic Question Mark

10x 50 Use the chart to identify mag. +4.9 Nu (ν) Ceti and hold it at the bottom half of the field of view. You'll see that it is the dot at the bottom of the 2.25°-long question mark asterism (an informal group of stars). This is a good star-party object, both because of its shape and the colours of the fainter stars that make up the rest of the asterism. ☐ **SEEN IT**

2. The Pisces Parallelogram

10x 50 If you follow a line up from mag. +2.0 Deneb Kaitos (Beta (β) Ceti; also known as Diphda) through mag. +3.5 Iota (ι) Ceti, you will find four stars of fifth magnitude (or so) that form a 3° x 1° parallelogram. The northeast corner is blue-white 29 Psc, and diagonally opposite is orange 30 Psc; the other two corners of the parallelogram appear yellowish. See how the parallelogram appears empty: it contains only one star brighter than eighth magnitude.
☐ **SEEN IT**

3. T Ceti

10x 50 Return to Deneb Kaitos and find the mag. +4.4 star 7 Ceti, 7° to the west. From there, go 2° to the southeast to T Ceti, the most westerly star in an equilateral triangle of sixth(ish)-magnitude stars, with a side of 1.5°. T Ceti is a semi-regular variable star (mag. +5.0 to +6.9) with a period of 159.3 days. If you observe it every couple of weeks you should be able to notice this variation.
☐ **SEEN IT**

4. 37 Ceti

10x 50 The double star 37 Ceti lies nearly 2.5° west of mag. +3.6 Theta (θ) Ceti. Its components are 49 arcseconds apart, which theoretically should be an easy split, even with lower magnifications, but the magnitude of the companion is only +7.9, which is 13 times less bright and can make splitting it a bit of a challenge. This is an optical double (a chance line-of-sight pairing), not a true binary star.
☐ **SEEN IT**

5. The Silver Coin Galaxy and NGC 288

15x 70 With a good clear southern horizon, find the right-angled triangle of fifth-magnitude stars 5° south of Deneb Kaitos. Look below it for a rhombus of fainter stars. You'll see the Silver Coin Galaxy (NGC 253) as an elongated glow about 1° beneath the rhombus. Next look slightly less than 2° in the direction of Alpha (α) Sculptoris, where you should see the faint glow of the globular cluster NGC 288. ☐ **SEEN IT**

6. Melpomene

15x 70 Asteroid 18 Melpomene has a very elliptical orbit with a period of 3.48 years, so approximately every seven years, when it's near its perihelion, it appears brighter than usual. It's at peak brightness (mag. +8.2) at the beginning of November. To identify it, observe its environs over several nights to determine which 'star' moves relative to the others. ☐ **SEEN IT**

☑ Tick the box when you've seen each one

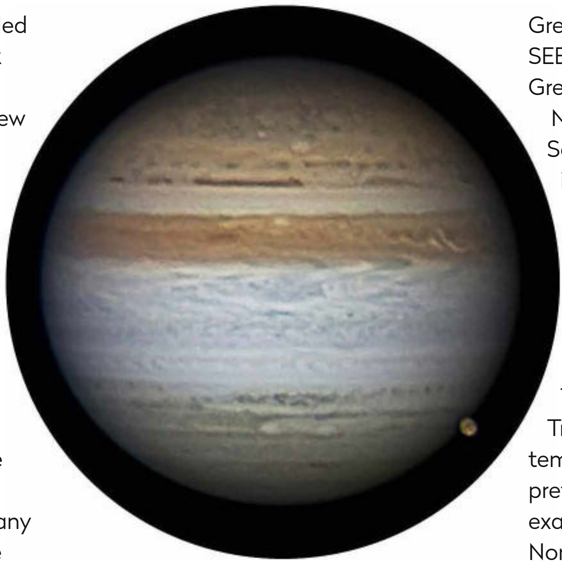
THE SKY GUIDE CHALLENGE

How many distinct belts and zones can you identify on Jupiter?

Jupiter is a gas giant with a thick, detailed and banded atmosphere. Any textbook typically shows a diagram identifying which bands are which. However, the view though the eyepiece doesn't always match what you'd expect. In this challenge, we're asking you to identify as many of Jupiter's belts and zones as possible.

Why doesn't Jupiter's atmosphere always resemble how it's depicted in books? Well, being a dynamic entity, the visibility of the belts and zones can vary. Turbulence can create conditions where they become indistinct from one another and sometimes disappear completely. As a result, it's best to use any diagram as a guide, first identifying the main features and then using these to navigate to the less obvious regions.

The best place to start is with the North and South Equatorial Belts (NEB and SEB). These are wide, dark belts easily seen through a small telescope. They encircle Jupiter's globe parallel to its equator. Between them lies the lighter Equatorial Zone (EZ) often filled with swirling atmospheric detail. At certain times this may show a thin, dark belt running midway between the NEB and SEB: the Equatorial Belt (EB). Although at first glance the NEB and SEB look similar, the SEB is split in two by the SEB Zone (SEBZ), the north and south components identified as the SEB(N) and SEB(S). The Great Red Spot (GRS) is embedded in the SEB(S) in a scalloped region called the Great Red Spot Hollow.

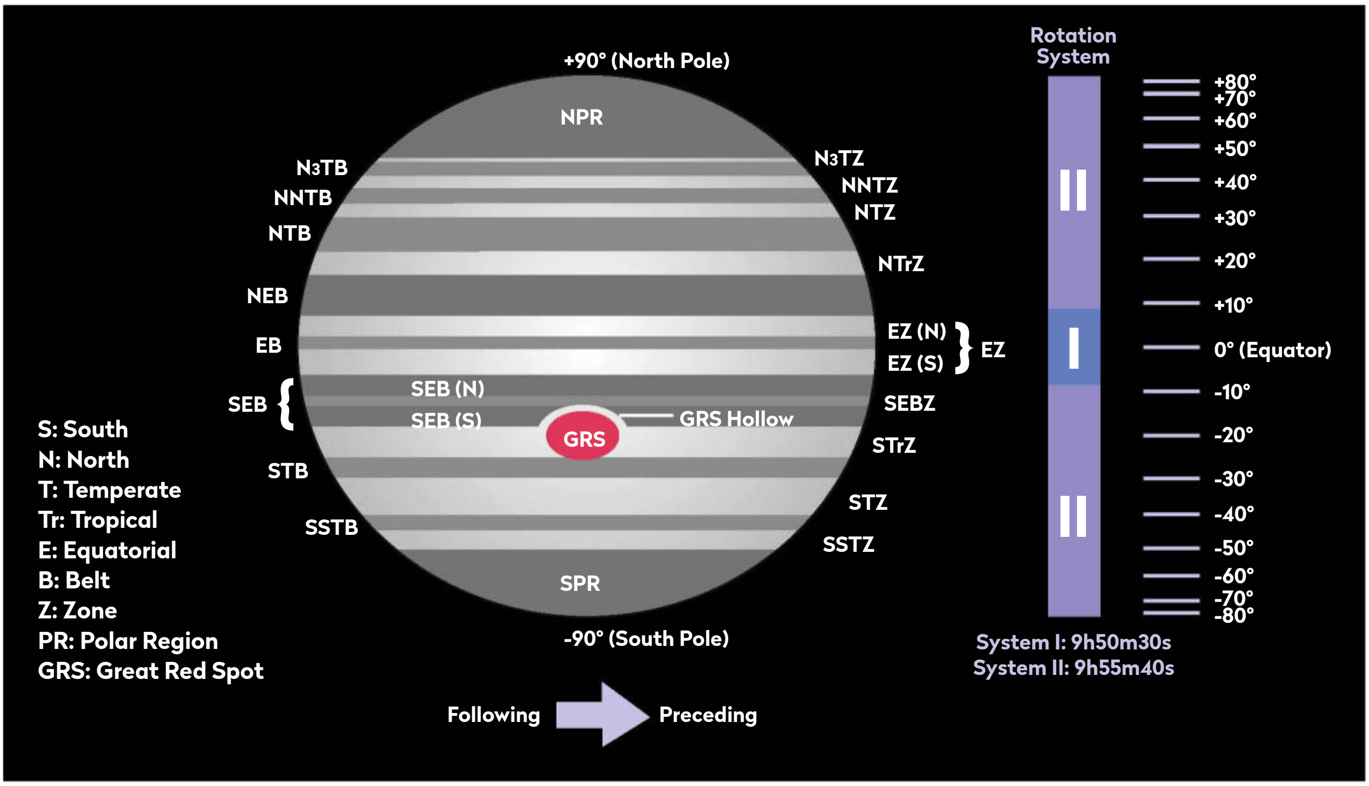


▲ **At irregular intervals even the SEB can fade from view, as last happened in 2010**

Near the poles are the dark North and South Polar Regions (NPR and SPR) and it's between a polar region and its nearest equatorial belt that the fun begins, because the belts and zones found here can be indistinct and somewhat confusing to identify.

North of the NEB and south of the SEB are two tropical zones: North Tropical Zone (NTrZ) and South Tropical Zone (STrZ). Then come the temperate belts (TB) and zones (TZ), prefixed by hemisphere identifiers. For example, North Temperate Belt (NTB), North Temperate Zone (NTZ), North North Temperate Belt (NNTB), North North Temperate Zone (NNTZ), and so on. The northern sequence ends with the North North North Temperate Belt and Zone, often labelled N3TB and N3TZ. The southern hemisphere's sequence ends with the SSTB and SSTZ.

See how many belts and zones you can identify, bearing in mind they may not be distinct and some may not be visible at all.



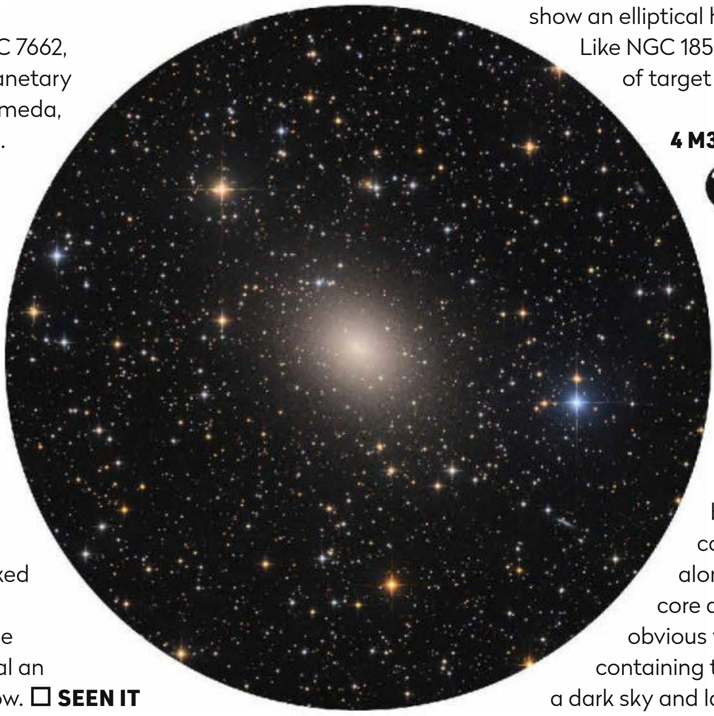
▲ **Belts and zones in Jupiter's atmosphere. Start by locating the main features, then use these to navigate to more ambiguous regions**

DEEP-SKY TOUR

Six majestic targets located between Queen Cassiopeia and her daughter Andromeda

1 NGC 7662

Our first target is NGC 7662, the Blue Snowball planetary nebula. This is located in Andromeda, 2.3° west and 0.7° south of mag. +4.3 Iota (ι) Andromedae or 0.4° south-southwest of mag. +5.8 13 Andromedae. It's a lovely example of a planetary nebula, bright and with a tangible non-stellar appearance even through a small scope. It shines at mag. +8.3 and has an overall diameter of around half an arcminute, although a typical view shows it half that size. A 150mm scope reveals a circular blue-green glow, easily overlooked at low magnification. A 250mm scope shows dark shading at the centre. Larger scopes may reveal an uneven edge to the nebula's glow. ☐ **SEEN IT**



▲ **See if you can discern the star-like point at the centre of large, diffuse galaxy NGC 185, the second target in this month's tour**

2 NGC 185

Next is a galaxy 12.4° east and 5.3° north of NGC 7662, within southern Cassiopeia. An easier route is to look 1° west of mag. +4.5 Omicron (ο) Cassiopeiae. NGC 185 is a satellite galaxy of M31 and suffers from low surface brightness. Although listed at mag. +9.2, its large apparent size of 11 x 10 arcminutes spreads its light across a large area. Having said this, it does have a well-defined core and through a 150mm scope shows as a 1-arcminute circular glow surrounded by an elongated 4-arcminute halo. Larger apertures reveal distinct granularity in the halo and there appears to be a star-like point at the centre of the core. ☐ **SEEN IT**

3 NGC 147

Also in Cassiopeia, located 1.9° west of Omicron Cassiopeiae or 0.9° west of NGC 185, is NGC 147, a dwarf spheroidal galaxy listed at mag. +9.5. Don't let that fool you though; this is a challenging target due to its large overall apparent size, similar to NGC 185: 13 x 8 arcminutes. Essentially, NGC 147 is a very-low-surface-brightness glow. It is best suited for larger instruments, but even here you'll be lucky to see much more than the glow of its core region. A 300mm instrument under dark-sky conditions will show an elliptical haze 3 x 2 arcminutes in size. Like NGC 185, this is also a satellite galaxy of target 4, M31. ☐ **SEEN IT**

4 M31

Our next target needs no introduction, M31 the Andromeda Galaxy being visible to the naked eye. M31 lies 7.2° south of Omicron Cassiopeiae or 1.3° west and slightly north of mag. +4.5 Nu (ν) Andromedae. It's mag. +3.5, but despite this can be telescopically challenging. Use a low power to get a beautiful overview of the bright core and a dark lane running along its northwestern edge. The core appears well defined, but lacks obvious visual features. The outer halo containing the spiral arms is faint, requiring a dark sky and large aperture. Numerous knots and clumps can be seen in the halo if you take your time. These include the star cloud NGC 206 located towards the halo's southwestern end. ☐ **SEEN IT**

5 M110

Messier's original catalogue contained 103 objects, a list augmented between 1921 and 1967 with eight additional entries. M110 was the last object added. It's a bright dwarf elliptical galaxy 37 arcminutes northwest of the centre of M31. Although listed at mag. +8.0, it has an extended size, appearing as an ellipse of roughly 10 x 3 arcminutes. This drops its surface brightness to a point where, although it looks bright next to M31 in photographs, through the eyepiece it can appear quite ghostly and fainter than you might expect. Use a medium power to get the best out of M110. If you assume M110 is associated with M31 you'd be correct, M110 being a close satellite of the giant spiral. ☐ **SEEN IT**

6 M32

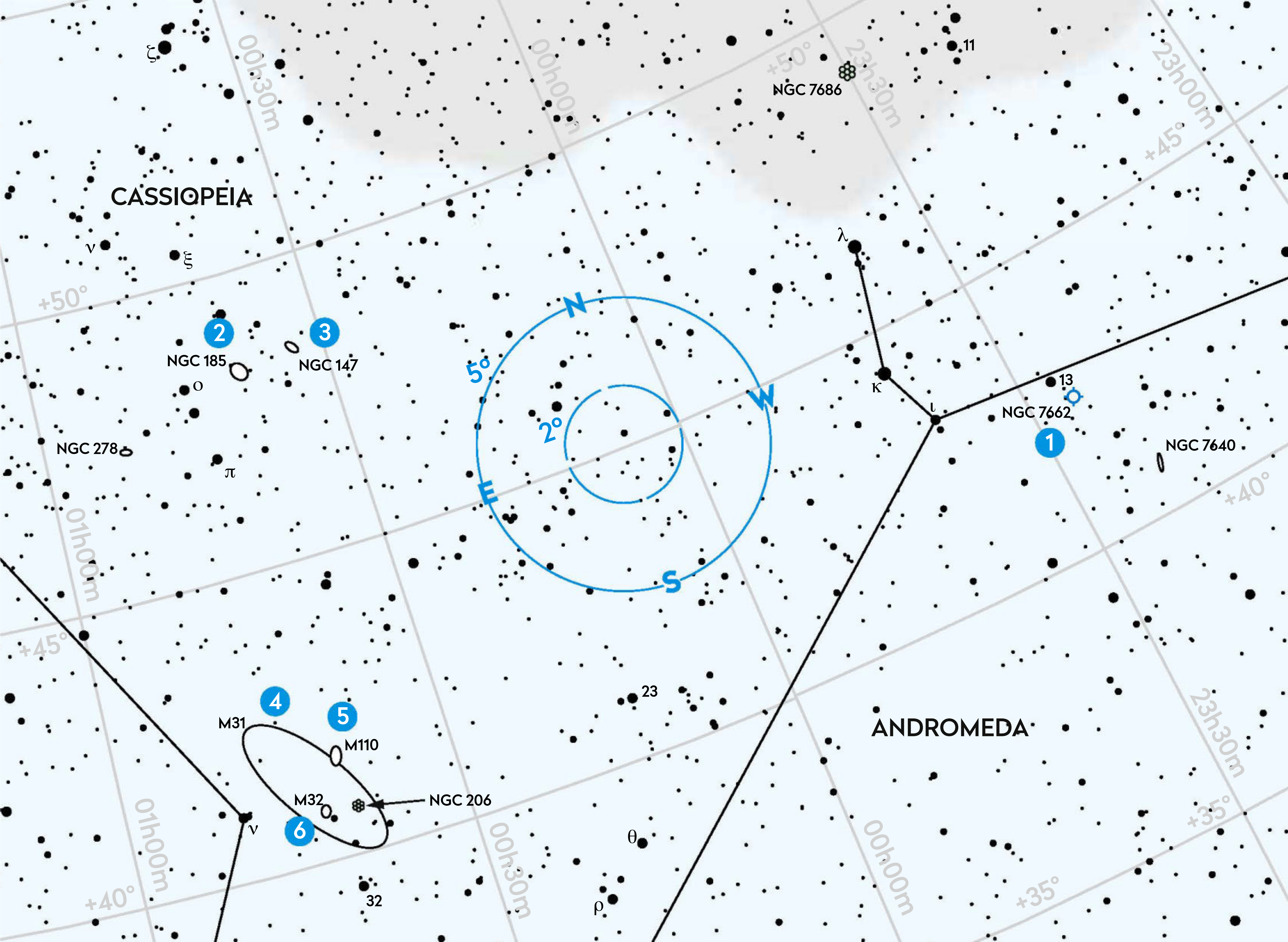
Our final target is easy to see. M32 is another satellite of M31, which this time appears within the confines of its larger host's outer halo. M32 has a magnitude slightly lower than M110 at mag. +8.2 and, despite its 8 x 6 arcminutes size, its core appears brighter. It sits 27 arcminutes due south of M31's core and appears distinct through a 150mm scope as a 3 x 2-arcminute glow, its elliptical elongation pointing towards M31's core. This is a dwarf 'early type' galaxy and as such has a relatively smooth, featureless appearance apart from the presence of its obvious core, which appears to brighten down to a star-like point. ☐ **SEEN IT**

SEBASTIAN VOLTMER/CCDGUIDE.COM, CHART BY PETE LAWRENCE

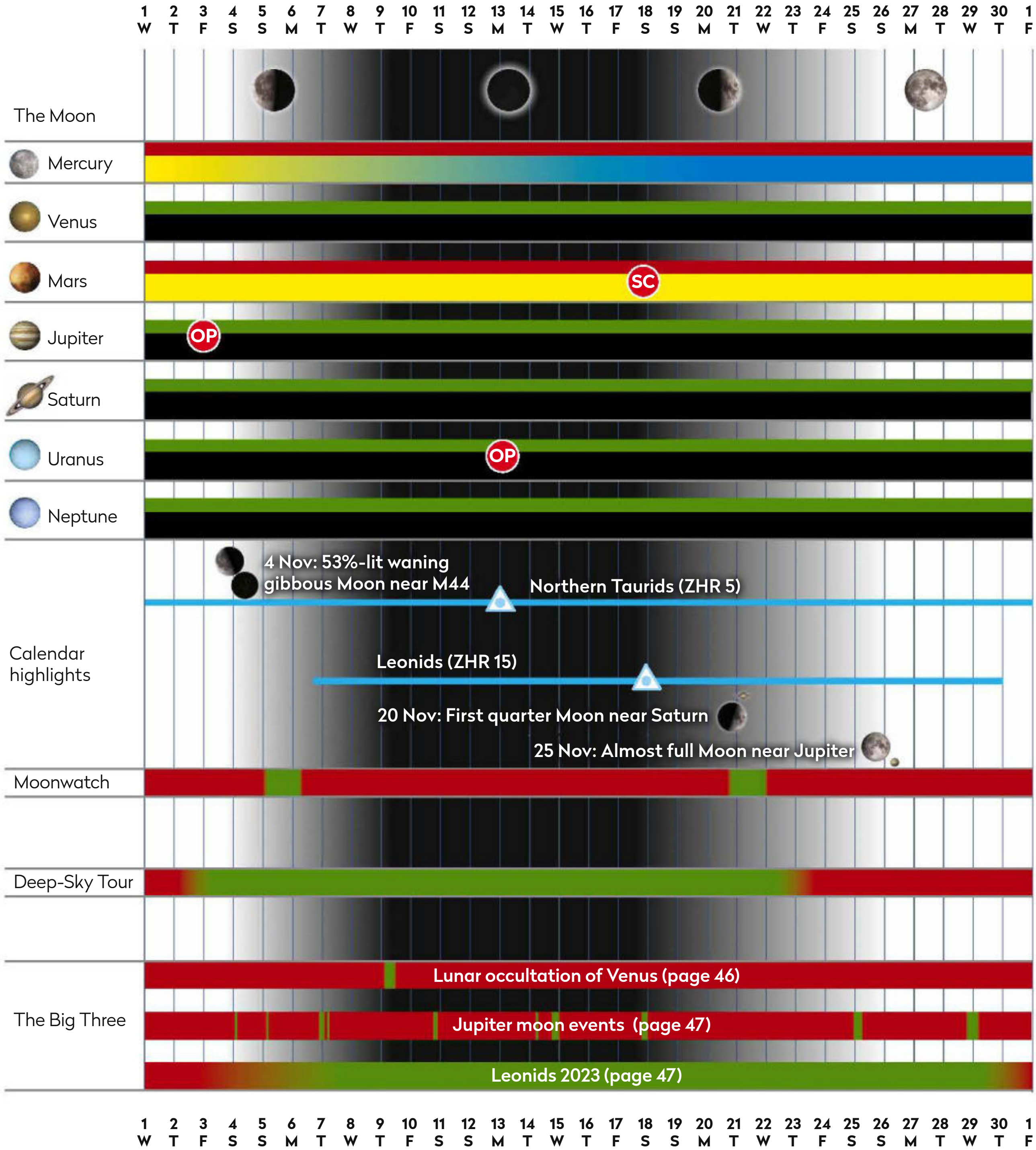
This Deep-Sky Tour has been automated
ASCOM-enabled Go-To mounts can now take you to this month's targets at the touch of a button, with our Deep-Sky Tour file for the EQTOUR app. Find it online.

More **ONLINE**

Print out this chart and take an automated Go-To tour. See page 5 for instructions


CASSIOPEIA
ANDROMEDA
NGC 7686
NGC 7662
NGC 7640
NGC 185
NGC 147
NGC 278
NGC 206
M31
M110
M32
1
2
3
4
5
6
N
S
E
W
5°
2°
11
13
23
32
00h30m
00h00m
23h30m
23h00m
01h00m
+50°
+45°
+40°
+35°

AT A GLANCE How the Sky Guide events will appear in November



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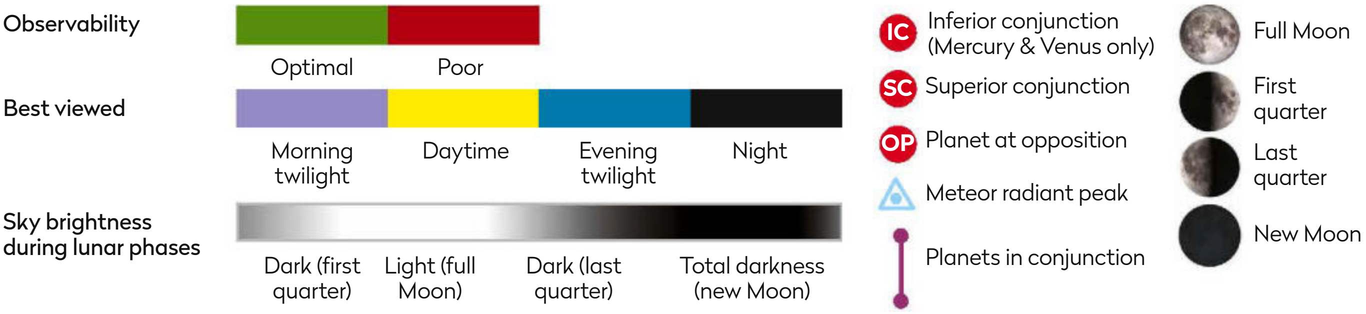
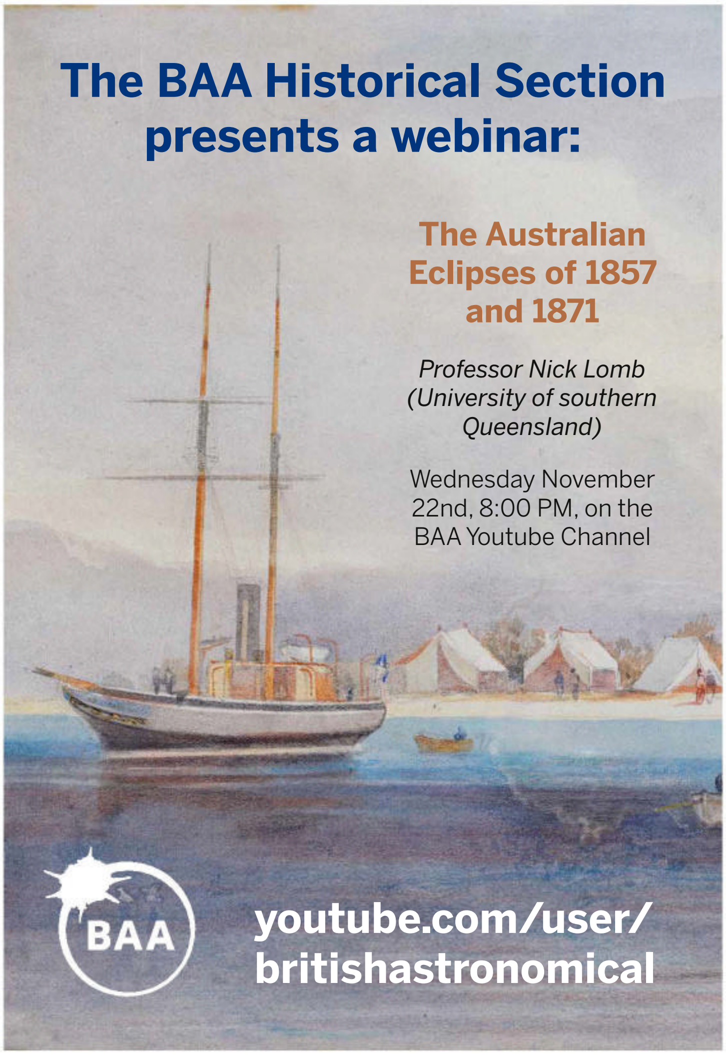


CHART BY PETE LAWRENCE

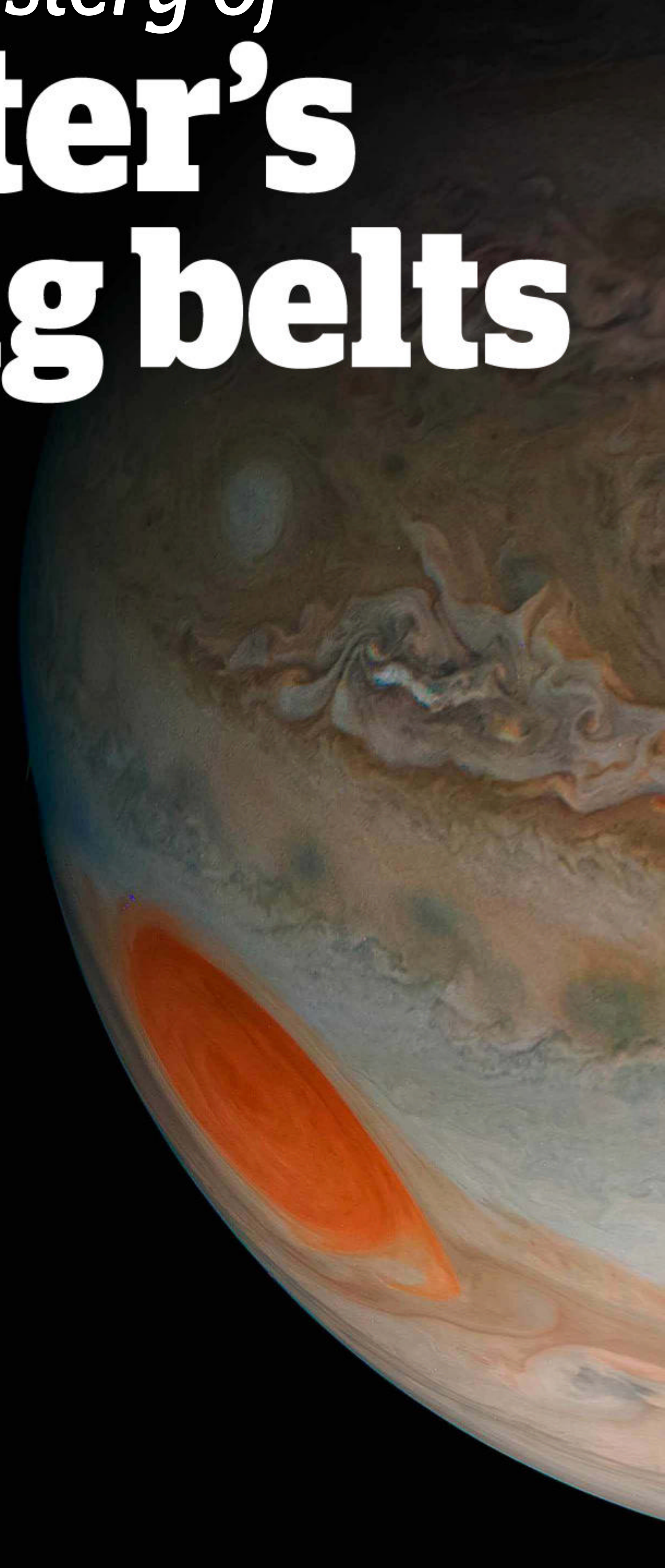

R237X/R238X
PADDED SOFTSHELL HYBRID JACKET & GILET
SUPREME BODY WARMTH IN SUPER SOFT, SUSTAINABLE FABRIC
GENUINE
recycled
by Result
shop.resultclothing.com


The BAA Historical Section presents a webinar:
The Australian Eclipses of 1857 and 1871
Professor Nick Lomb (University of southern Queensland)
Wednesday November 22nd, 8:00 PM, on the BAA Youtube Channel
BAA
youtube.com/user/britishastronomical


Ri
The Royal Institution
Science Lives Here
Your chance to be part of the
lights, camera ... action!
Image credit: Paul Wilkinson Photography

Solving the mystery of

Jupiter's shifting belts



ENHANCED IMAGE BY KEVIN M. GILL (CC-BY) BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS

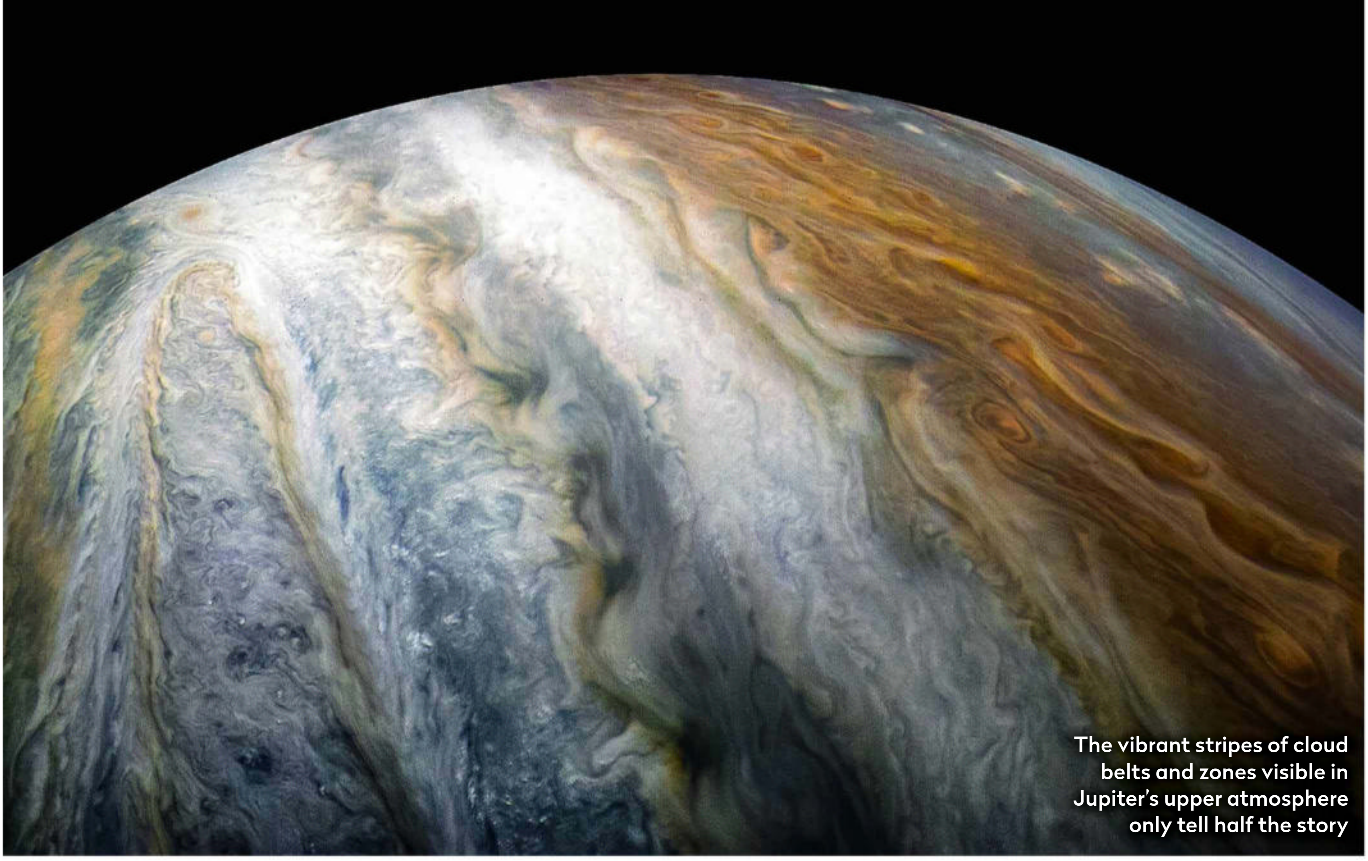
Jupiter's beautiful stripes move and morph from year to year. **Giles Sparrow** finds out how the Juno spacecraft revealed where these changes begin

Step out under the stars this month and you won't be able to miss Jupiter. As well as being the largest planet in our Solar System, it is also at opposition this month, meaning it lies directly opposite the Sun as seen from Earth. That means the giant planet is not only visible all night but is also at its closest to us, giving backyard astronomers a great chance to observe its colourful cloud bands. These ever-changing patterns have fascinated sky-watchers for centuries, but now an international team of scientists say they've come a big step closer to understanding what drives their behaviour.

Jupiter is a bloated gas giant that could swallow 1,300 Earths, but it's composed almost entirely of the lightweight gases hydrogen and helium. The uppermost layers of its deep atmosphere are wrapped in bands of cloud that run parallel to the planet's bulging equator. Darker regions dominated by reddish, brown and blue clouds are called belts, while lighter, cream-coloured stripes are known as zones.

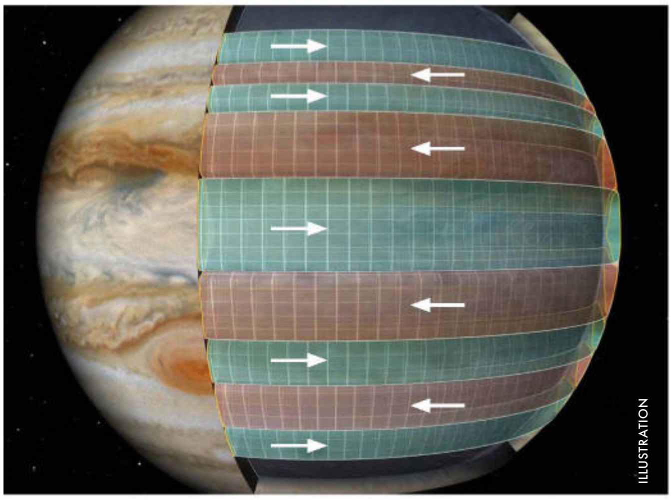
The striking colour differences between belts and zones are due to the way that various chemicals condense from gas into clouds of ice crystals or liquid droplets in different conditions. ▶

In orbit around the gas giant since 2016, Juno has looked deeper into the secrets of its swirling cloud bands than any previous mission



The vibrant stripes of cloud belts and zones visible in Jupiter's upper atmosphere only tell half the story

▶ The bright zones mark areas where gas is welling up from Jupiter's interior, rising a few kilometres higher than their surroundings into colder, lower-pressure surroundings where crystals of ammonia ice can condense and form creamy-white clouds. The dark belts, in contrast, mark areas where gas is sinking deeper into the atmosphere, experiencing warmer temperatures and higher pressures. The clouds that condense in these conditions are made mostly from ammonium hydrosulphide, ammonium sulphide and water – although none of these chemicals can themselves explain the distinctive colours of the belts, which are probably due to a 'soup' of more elusive chemical compounds.



▲ **We now know that jet streams deep beneath the cloud bands move in alternate directions, whipped by stupendous winds, and at different altitudes**

Jupiter can change its stripes

Alternating zones and belts form a series of stripes to the north and south of Jupiter's equator, with each distinctive band named after the latitude where it resides. So the broad Equatorial Zone around the equator itself is bounded by the North and South Equatorial Belts, then the North and South Tropical Zones, and so on. What's more, colour isn't the only difference between the cloud bands – they are also moving in opposite directions across the surface.

"If you look a little bit more closely, you can see clouds zipping around, carried by extraordinarily strong easterly and westerly winds," says Professor Chris Jones from the University of Leeds, an expert in planetary magnetic fields and the winds of giant planets. "Near the equator, the wind blows eastward, but as you change latitude a bit, either north or south, it goes westward. And then if you move a little bit further away it goes eastward again. This alternating pattern of eastward and westward winds is quite different from weather on Earth."

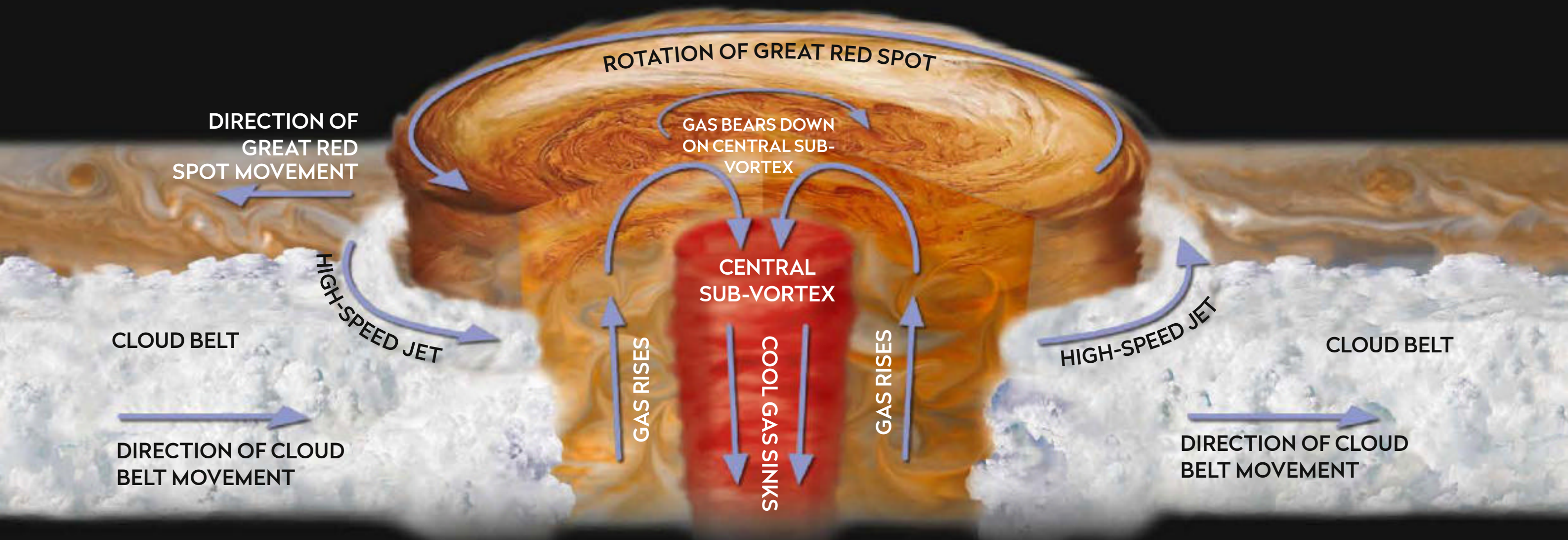
Wind speeds on Jupiter can reach hundreds of kilometres per hour and are at their strongest in jet streams that mark the boundaries between belts and zones. Opposing streams can also set large masses of air rotating, giving rise to oval storms where colours are often at their most intense.

Yet because the belts and zones have been broadly stable through centuries of telescopic observation, the fact that they can go through major upheavals every few years – before settling down again – is often overlooked. "Every four or five years, things change," explains Professor Jones. "The colours of the belts can change and sometimes you see global upheavals when the whole weather pattern goes slightly haywire for a bit."

In 2007, for instance, the Hubble Space Telescope captured stunning images showing Jupiter's entire north tropical zone turning suddenly brown and apparently merging with the belts on either side. Simultaneously, a darker streak spread along the edge of the equatorial belt just north of the equator, marking a spreading rent in the clouds that revealed darker layers below.

The transparency of the clouds has a great effect on Jupiter's heat output, as recorded by infrared images of the planet. Gravitational contraction – the slow sifting of heavier elements towards the centre of Jupiter – acts as a powerful internal energy source,

ENHANCED IMAGE BY KEVIN M. GILL (CC-BY) BASED ON IMAGES PROVIDED COURTESY OF NASA/JPL-CALTECH/SWRI/MSSS, NASA, ILLUSTRATION BY PAUL WOOTTON, NASA/JPL-CALTECH/SWRI/MSSS/IMAGE PROCESSING BY KEVIN M. GILL/© CC BY, NASA/ESA/A. SIMON-MILLER (NASA GODDARD SPACE FLIGHT CENTER) A. SÁNCHEZ-LAVEGA/R. HUESO AND S. PÉREZ-HOYOS (UNIVERSITY OF THE BASQUE COUNTRY) E. GARCÍA-MELENDO (ESTEVE DURAN OBSERVATORY FOUNDATION/SPAIN) AND G. ORTON (JET PROPULSION LABORATORY)



▲ What lies beneath: Juno's measurements, gathered as it was jostled by the storm as it flew by, suggest the Great Red Spot could extend a massive 300km down into the planet's atmosphere

The Great Red Spot

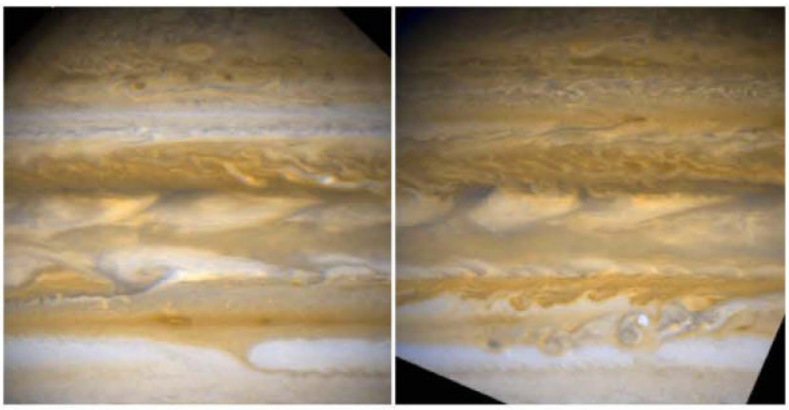
Although it's Jupiter's most constant feature, the giant storm has changed over the years

The Great Red Spot (GRS) is Jupiter's most famous feature, a vast storm that has been observed continuously for almost 200 years and was probably first spotted in 1665. Sitting on the edge of the South Equatorial Belt, it is confined between a strong westward jet stream to its north and a weaker eastbound one to its south. Winds along the edge can exceed 430km/h as it spins counter-clockwise (turning once every six Earth days), but the central eye of the storm seems largely stagnant.

While most of Jupiter's darker features are lower-lying than the pale clouds of the zones, the top of the GRS soars to 8km above its surroundings. The source of its colour (which can vary from intense red to a salmony-pink and sometimes disappears completely, leaving just a 'hollow' in the surrounding weather systems to reveal the spot's presence) is still unknown. However, most scientists believe it is created by chemicals welling up from deep inside the planet and perhaps undergoing reactions on exposure to sunlight.

In 2019, Juno made two low passes over the spot, allowing scientists to probe beneath the surface by looking for slight deflections in the probe's path caused by concentrations of mass (and higher gravity) in the region. These confirmed that the GRS probably extends to 300km beneath the cloud tops.

The GRS changes colour and occasionally disappears from view altogether



▲ Bands of white cloud turn brown in a dramatic example of Jupiter's ever-changing face, captured by Hubble between March (left) and June (right) 2007

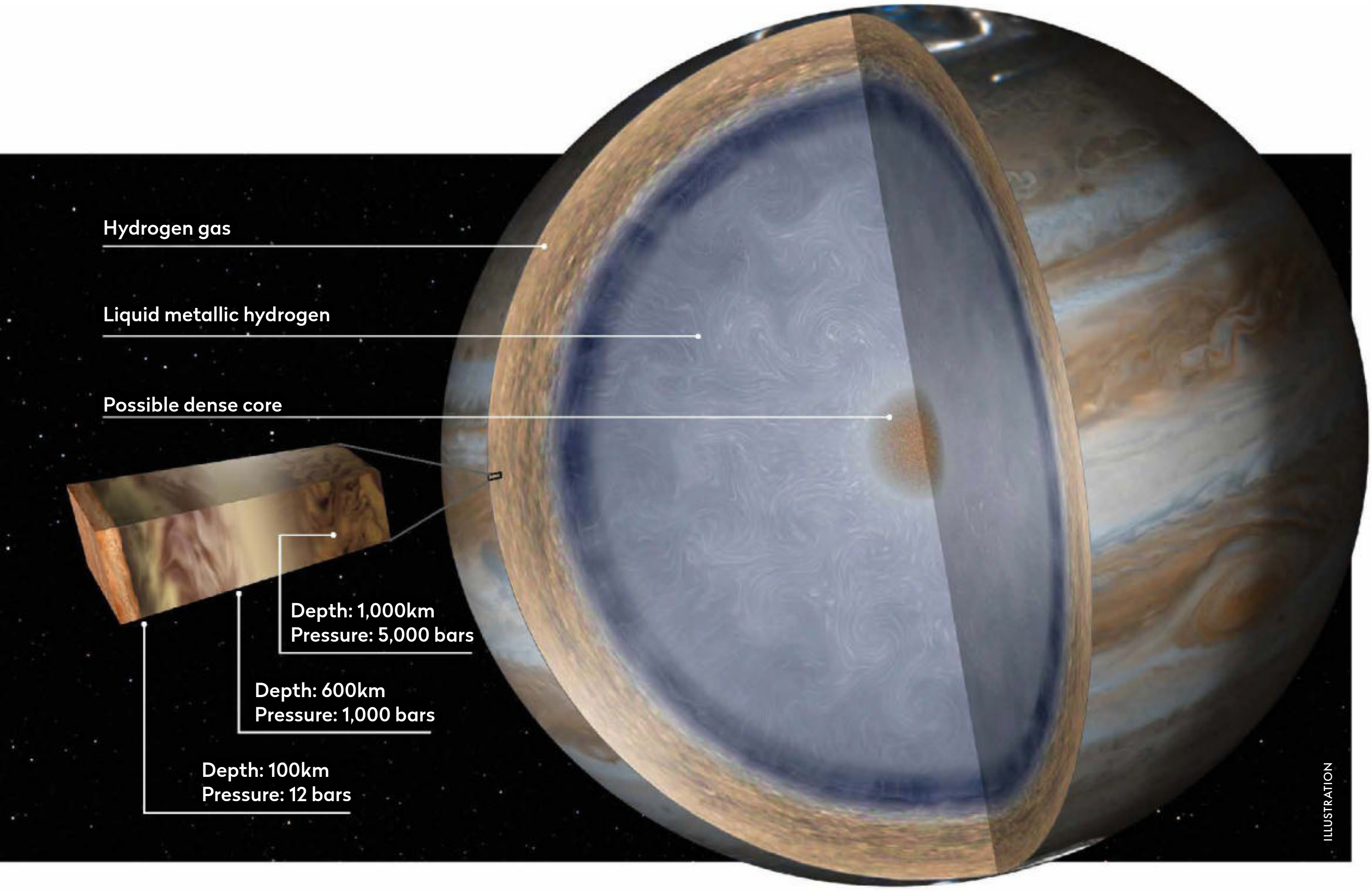
allowing the planet to emit twice as much heat as it receives from the Sun. Clouds of different kinds may be either transparent or opaque to the escaping heat, resulting in dramatic changes of intensity in infrared views.

This relationship also works in reverse, however – variations in heat from the interior can affect which chemicals condense into visible clouds at various times in different regions. In fact, infrared measurements have for some time suggested that temperature variations some 50km beneath Jupiter's cloud tops are the driving force behind the periodic changes at the surface.

Going deeper

Professor Jones, his former Leeds University colleague Dr Kumiko Hori (now at Japan's Kobe University) and others were keen to investigate the cause of the temperature changes themselves. To do this, they needed to look even deeper inside the gas giant world, to study its powerful, ever-changing magnetic field.

Even though Jupiter's interior consists almost entirely of hydrogen and helium, it still has distinct internal layers. From around 1,000km down, the pressure from above is so great that these lightweight gases are compressed to liquid form in a global ocean. The hydrogen within this vast sea remains in molecular form (with two hydrogen atoms bonded together to make an H_2 molecule), but from around 20,000km down (just over a quarter of the way to the centre), the pressure grows so great ▶



▶ that these molecules are split apart. The result is a dense sea of electrically charged, free-floating hydrogen ions. Bulk motions within this 'liquid metallic' hydrogen create powerful electric currents deep inside Jupiter, and as the giant planet spins on its axis in just under 10 hours, these swirling currents can in turn generate an enormous magnetic field. In fact, Jupiter's vast magnetosphere is 20,000 times more intense than Earth's, and its effects can be felt as far away as the orbit of Saturn.

Until recently, the detailed structure of Jupiter's magnetic field has been a mystery, locked away from direct observation along with other secrets of the gas giant's interior. However, thanks to data from NASA's Juno space probe, it's now possible for scientists to map the field in detail and build mathematical models of what's going on inside Jupiter.

Using one such model, Hori, Jones and their colleagues worked out how the jet streams visible at Jupiter's surface would interact with the swirling metallic fluid far below. They found that the internal field is subjected to so-called 'Alfvén waves'. These slow-moving waves are generated by torsion – twisting of the overall magnetic field – and when viewed from outside, they seem to rotate much more slowly than the magnetosphere itself. One consequence is a slow-moving hotspot of intense magnetism that moves east and west in a long, slow oscillation. Juno's observations support these predictions through their detection of an invisible, powerfully magnetised region that scientists have dubbed the Great Blue Spot.

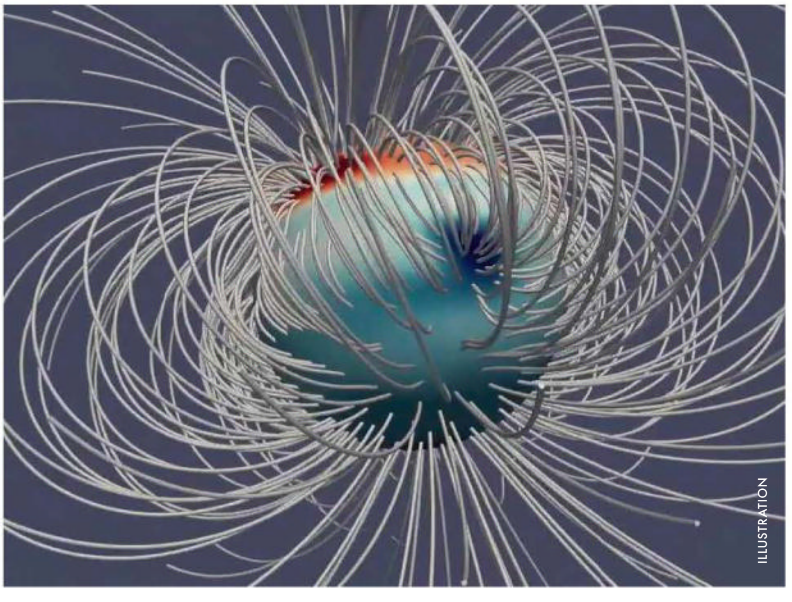
Hori's model predicts that, as Jupiter's jet streams and interior influence each other, the precise position of the Great Blue Spot not only wanders around the planet, but also sometimes reverses. The periods of the simulated reversals seems to match very well with the multi-year cycles of variations seen especially in Jupiter's North Equatorial and North Temperate belts. For most of Juno's mission at Jupiter, the spot has been moving slowly eastwards, but its motion is currently slowing and the researchers suspect this could be the trigger for a forthcoming change of direction, accompanied by disruption to the cloud bands above.

▲ The inside story: Juno's fly-bys have revealed Jupiter's deep atmospheric layers and suggest a 'fuzzy' heavy-element core

▼ The mysterious Great Blue Spot, an invisible hotspot of magnetism, appears to wander around the planet

Magnetic mystery

"There remain uncertainties and questions, particularly how exactly the torsional oscillation produces the observed infrared variation," points



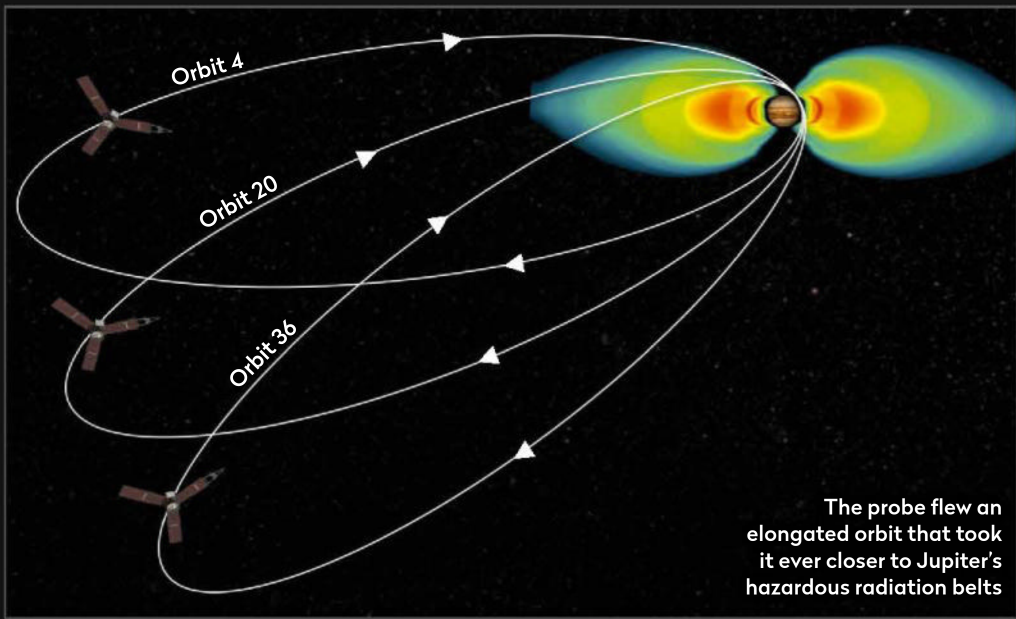
NASA/JPL, NASA/JPL-CALTECH/HARVARD/MOORE ET AL, NASA/JPL-CALTECH, NASA/JPL-CALTECH/SWRI/MSSS/IMAGE PROCESSING BY DAVID MARRIOTT

Probing Jupiter's magnetism

The planet's intense magnetic field makes it a dangerous place to study

Studying Jupiter's magnetic field in detail presents a huge challenge, not only because of the difficulty of sending probes to the giant planet, but also because the field itself traps a series of doughnut-shaped radiation belts around the planet (similar to Earth's Van Allen belts, but far more intense). For the Galileo mission (1995–2003), the first spacecraft to orbit Jupiter, these belts were a hazard to avoid, since bombardment with their high-energy particles could damage sensitive instruments. When Juno arrived in July 2016, on a mission to specifically study the magnetic field and interior, it therefore took up an unusual elongated orbit over Jupiter's poles. For most of the time, the probe remains at a safe distance well beyond the radiation belts (up to 8 million kilometres from Jupiter). However, as it approaches the plane once in each orbit, it picks up speed as it plunges towards a daring fly-by as close as 4,200km above the polar cloud tops.

This choice of orbit ensues Juno endures as little radiation as possible, and NASA engineers hoped it might survive 37 orbits and last for around three years. Fortunately, the spacecraft has shown surprising durability, allowing NASA to extend its planned mission by several years. Juno should now complete a total of 76 orbits, ending with a spectacular atmospheric plunge in 2025 that will destroy the probe and ensure the surfaces of Jupiter's moons remain uncontaminated. The probe's extended mission has provided new insights into how the magnetic field changes over multi-year timespans, as well as permitting close fly-bys of Jupiter's largest moons.



The probe flew an elongated orbit that took it ever closer to Jupiter's hazardous radiation belts

out Dr Hori. One possible link between magnetism and the colour and dynamics of Jupiter's clouds, for instance, could lie in the way that intense magnetic fields can stall or divert the upwelling of hot gas rising to the surface (a similar motion creates the cool, dark patches in the solar atmosphere known as sunspots). However, while there's much more research needed to establish the nature of the connection, the team are confident that a connection is there, and that Jupiter's weather goes through cycles influenced by its changing magnetic field.

What's more, now this link has been found, scientists might one day be able to use it in reverse. "I hope our paper could also open a window to probe the hidden deep interior of Jupiter," says Dr Hori, "just like seismology does for the Earth and helioseismology does for the Sun."

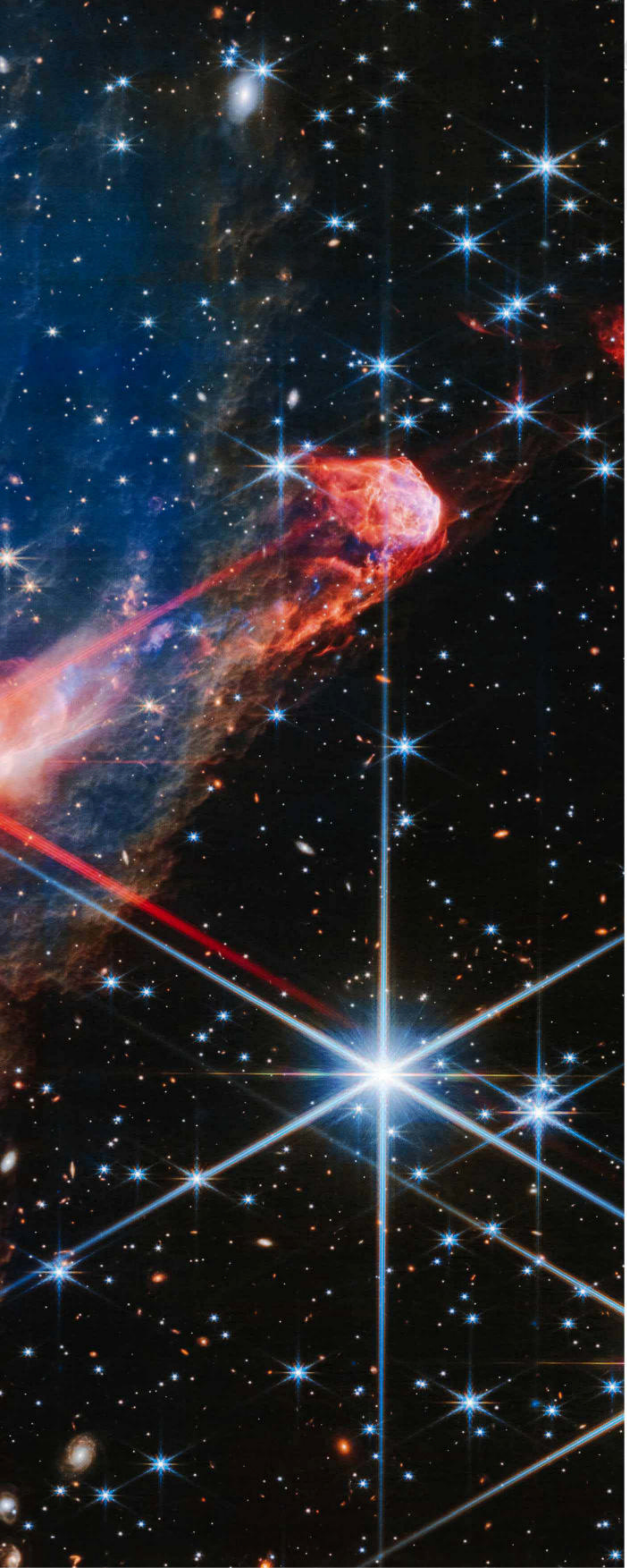
There's a long way to go before our external view of Jupiter's ever-changing cloudscapes can be put to use in measuring the state of the planet's magnetic field and internal structure. In the meantime, Juno's help in unveiling the mystery of Jupiter's atmospheric eruptions is just one of the spacecraft's major achievements. Hopefully there will be many more to come before the mission reaches its end in 2025.


Thanks to Juno, researchers understand Jupiter better than ever before, but there are plenty of secrets still to uncover


Giles Sparrow is a science writer and fellow of the Royal Astronomical Society

Image processing EXPLAINED

Lead Image Processor for the James Webb Space Telescope, **Joe DePasquale** explains how you can apply the processes he uses to create JWST's stunning images to enhance your own astrophotos



On a recent trip to London, my family and I had a chance to visit the Royal Observatory in Greenwich. I've always been fascinated by the challenges faced by sea-faring explorers of the 18th century, who needed accurate methods to track a ship's location on the ocean but hadn't cracked the problem until John Harrison perfected his marine chronometer in 1759 (which is on display in the observatory). We can draw direct parallels between space-based observatories – seeking answers to the big questions about our place in the Universe – and those intrepid oceanic explorers who set sail with the goal of exploring the unknown reaches of the world. The James Webb Space Telescope, with its huge sun shield deployed like the sail of a cosmic ship, is the latest of our great explorers, orbiting an imaginary point a million miles away as its giant golden mirror array captures light that has been streaming across the Universe for billions of years.

How lucky are we to live in a time when we can work with this ancient light? And not only Webb – even a decent backyard telescope is capable of providing views of the cosmos that would have blown the wig off of any Astronomer Royal in Greenwich! Many of the techniques I use in processing Webb data are easily transferrable to data obtained from backyard telescopes. Let's journey through the process of working with calibrated data from any telescope, transforming it into colourful views of the cosmos. ▶

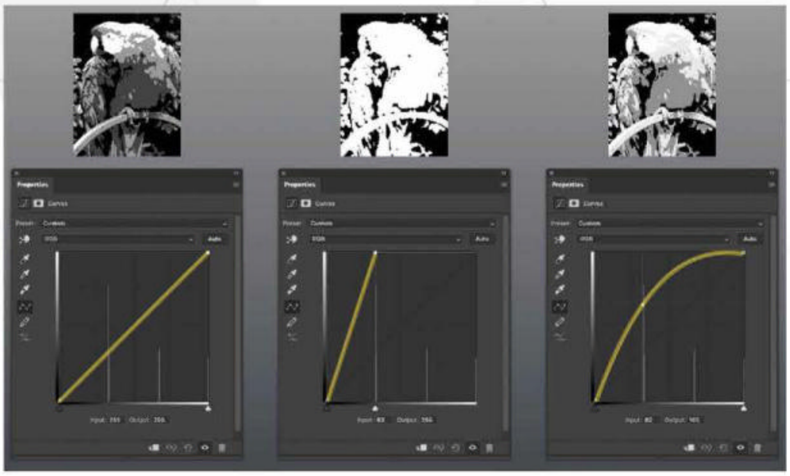
Joe DePasquale is the Lead Image Processor at the Space Telescope Science Institute, Baltimore, USA, the home of science and mission operations for the James Webb Space Telescope

◀ **You can follow just the same steps for your astro images as Joe used for this JWST image of Herbig-Haro 46/47**

Data stretching

What exactly do we mean by 'stretching', and why do we need to do it? Stretching here refers to the values of the individual pixels that make up the image. Modern charge-coupled devices (CCDs) are so sensitive to light that the images they produce have an enormous dynamic range, far beyond what can be seen with the eye. In a 16-bit monochromatic image, each pixel can be one of 65,536 different shades of grey. This specific number is directly related to the digital nature of the data. A bit can be one of two values, 0 or 1. In a 16-bit image, each pixel holds a value defined by a sequence of 16 bits where 0000000000000000 is pure black and 1111111111111111 is pure white. The total amount of possible values is found by taking 2 to the 16th power, or 65,536.

For simplicity, let's consider this 2-bit image of a parrot. The total possible pixel values from black to white will be 2 raised to the 2nd power, or 4. With only four possible values, we can actually name them! Each pixel can be either black, dark grey, light grey, or white.



▲ Three versions of a simple 2-bit greyscale image in which the pixel values have been changed using a curves adjustment

This simple image also helps us define the histogram. Imagine if all of the pixels fell to the floor and you want to organise them by their brightness. Each pixel can go into one of the four bins that we just defined. When you've accounted for all of the pixels, you've created a histogram!

If we want to make this image brighter, we need to change the pixel values using an image-processing application like Photoshop or the freely available GIMP. A curves adjustment tool from one of these programs allows you to alter the values of the pixels

RICARDO CANCHO NIEMIETZ, J. DEPASQUALE, NASA/ESA AND THE HUBBLE HERITAGE TEAM (AURA/STSCI), NASA/ESA/AND B. HOLWERDA (UNIVERSITY, NOIRLAB/IPAC/ESA/STSCI/CFA FITS LIBERATOR 4 OF LOUISVILLE)

Is what JWST sees real?

With so much processing applied to the raw data from space, it's the question many will wonder about

Given the drama of Webb's images, it's only natural to question whether what we are seeing is real. I can answer most emphatically that everything you see in the images from Webb is 100 per cent real! Webb sees the Universe in infrared wavelengths, a kind of light that is beyond what our eyes are capable of perceiving. As image processors, we take advantage of the way our eyes see colour to translate these infrared wavelengths into colours that our eyes can perceive. It's not unlike transposing music from one octave to another. The relative pitches between notes stay the same, but overall the music shifts to either higher or lower notes. This method of colourising the data – what we refer to as representative colour – gives us a powerful tool to explore the Universe in many wavelengths beyond visible light.

The processing team faithfully maps Webb's infrared data into colours we can perceive

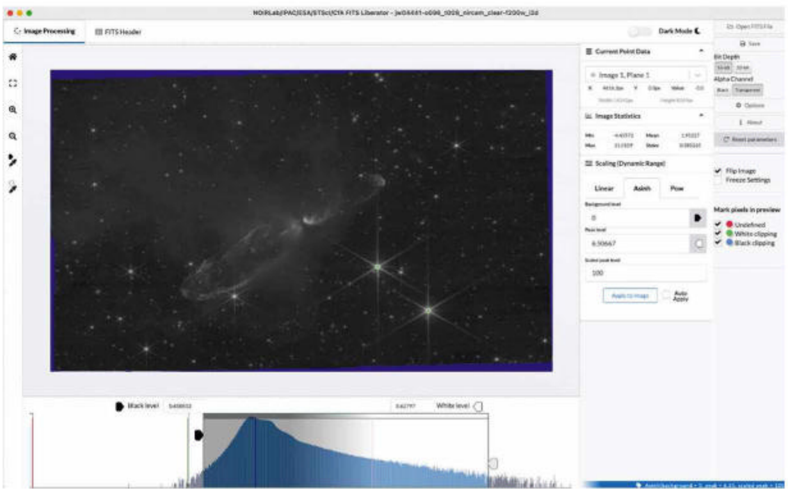
▲ **A non-linear stretch of a spiral galaxy should strikes a balance between the bright core, any foreground stars, the nuggets of gleaming star formation and the faint arms**

▼ **FITS Liberator working with JWST data for HH 46/47, the image at the start of this feature**

across the entire histogram. We can alter the pixels so that dark grey becomes light grey, and light grey becomes white. This is a linear change, altering the white point of the image; while it is brighter, we've lost some information. Instead, we apply a non-linear change to the pixel values, preserving the details of those white pixels while raising the light gray and dark gray pixels to a higher value.

In astronomical images we use non-linear transformations to allow us to see the faint details hiding in the darkness and preserve the bright details.

Take a spiral galaxy. You see a bright core surrounded by much fainter spiral arms of light, dotted with bright regions where stars may be forming. Composing an image like that requires systematically brightening the data to allow us to see those faint spiral arms and also see the bright inner core. This is what image stretching is all about, and why it is one of the most important parts of producing a quality astronomical image.



There are many tools available for stretching astronomical data. A great free option is NOIRLab's FITS Liberator (**noirlab.edu/public/products/fitsliberator**), a standalone tool that works on PC or Mac. Its intuitive interface allows you to explore the pixel values in your image and stretch them as you see fit. The 'Asinh' option under 'Scaling (Dynamic Range)' provides a great starting point for stretching. Try loading your data, setting the Scaling to Asinh, then setting the 'Scaled peak level' to 100, ensuring that the black and white point sliders encompass the bulk of the data in the bottom histogram.

Data calibration

One of the benefits of working with data from professional observatories like Webb is that it is already fully calibrated, allowing you to jump right in at the point of composing a colour image. If you're working with your own telescope data, you'll want to have those calibration steps taken care of before starting here. However, even fully calibrated data will still contain artefacts of the imaging system like cosmic rays, reflections, uneven background levels and saturated data. After you've stretched the data, you may notice these artefacts. This is a good time to start addressing them; this cleanup work will likely continue through the following sections as well.

Example artefacts from Webb data are the black cores that we see in bright stars, which are actually a result of the calibration process flagging saturated pixels. I deal with this issue using an adapted script in PixInsight (available here: **bit.ly/PixelClipJDP**) which replaces those black pixels with surrounding white pixels. A similar result could be achieved through the use of the 'Color Range' selection tool in Photoshop, carefully set to flag pixels below a certain threshold and then set them to white. ▶

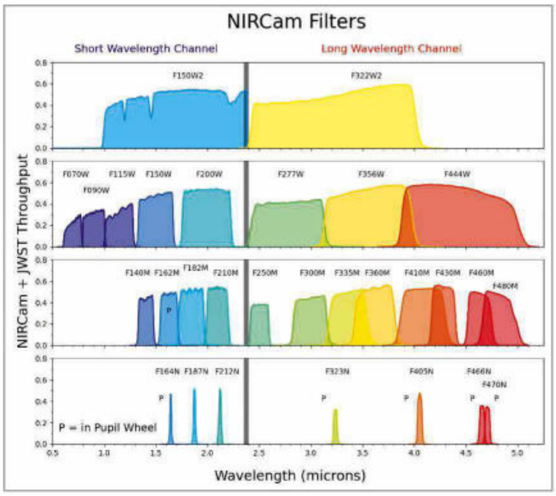
Working with colour

Colour in astronomical images comes from the use of filters when obtaining the data. Filters separate the light we're observing into very specific wavelength ranges. Even the cameras in our cell phones use filters to produce colour images, but those filters are usually

▲ **Demonstrating the breakdown of a digital image into separate red, green and blue colour channels**

built into the pixels so we never see them. Webb's NIRCam instrument has 29 bandpass filters, providing astronomers with an array of options for capturing their data. Similarly, cameras developed for ground-based astrophotography use filters to provide the necessary data for a colour image.

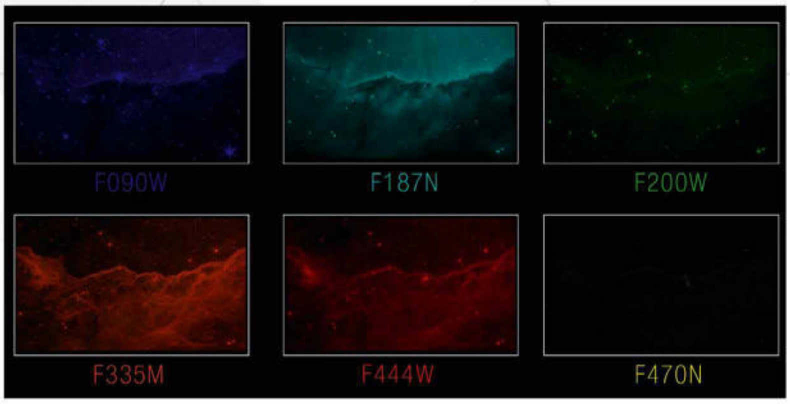
A basic colour image would be composed from three wideband filters, combining light from a red filter with light from green and blue filters. The data is grayscale, so colour is applied in an image-processing application and we use a chromatic



▲ **The full suite of filters available for the NIRCam, showing each filter's ability to allow specific wavelength ranges of light through to the detector**

ordering to apply colours systematically. In the case of R, G and B filters, this is very straightforward. Chromatically ordering the data means that we apply colour according to wavelength, with the longest wavelength being assigned red, the medium wavelength green and the shortest wavelength blue. We use this same approach with Webb data, even though the light captured by Webb is infrared.

I apply colour either in PixInsight with the use of the PixelMath tool or in Photoshop using adjustment layers. You could also try using GIMP to apply colour to astronomical data. As you're combining data in colour, watch out for any calibration issues like cosmic rays. They can be dealt with by finding the offending pixels and replacing them with the average value



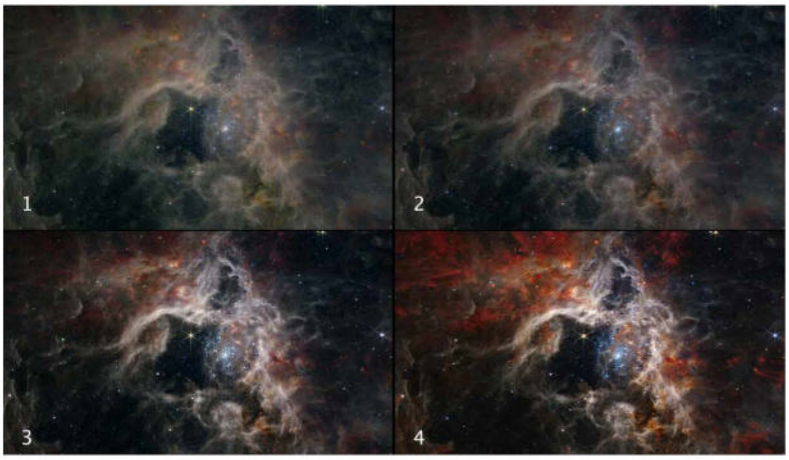
▲ **How JWST's 'Cosmic Cliffs' splits into its component colour channels according to wavelength, as determined by the filter used**

of nearby pixels, being careful not to add or remove anything that wasn't already there in the data.

Colour balancing and image composition

Congratulations on making it this far into the process! By now, you've found the best stretch for your data and applied colour chromatically. You could stop here, but you would be missing out on some very important steps in this process. Colour balancing and tonally adjusting your image can turn your image into something truly spectacular. Not all filters allow the equivalent amount of light to pass through, so we need to balance the filter contributions in the final composite image to avoid any colour imbalances.

At the very least, you'll want to make sure that the blank sky background of your image is roughly a neutral dark grey. If your image contains face-on spiral galaxies, they make an excellent white



▲ **Balancing the colours in the JWST image of 30 Doradus, from initial colour composite to finished image**

reference point. This can be done in PixInsight using the 'ColorCalibration' tool or in Photoshop using curves adjustment layers. Once content with your colour balance, you can make some final tonal adjustments, again using curves, with an eye towards obtaining a good overall contrast across the image. I prefer my blank sky background to be slightly above absolute black, and I make sure that the brightest parts of my image are pure white without being overly saturated.

Finally, consider the composition of your image. Does it roughly follow the rule of thirds? Are there

The meaning of colour in astro images

Far from being just a pretty add-on, colour is a crucial part of decoding scientific information in images

As beautifully vibrant and detailed as images from Webb are, the colours are not arbitrarily chosen. They have real scientific value. The process of applying colour chromatically according to wavelength gives us more information in the final image than we would have from a single grayscale image.

For example, in deep-field images littered with galaxies, colours play a vital role in giving us a visual cue to the most distant galaxies in an image. The faintest red smudges are likely very distant galaxies formed within a few hundred million years after the Big Bang. Similarly, in images of nebulae within our Galaxy, colours clue us in to the different chemical processes taking place within the nebula. We can get a sense of the distribution of different elements within the nebula through the use of chromatically ordered colour. It's more than just a pretty picture!

Colour helps us navigate JWST's data deluge. Red, for example, is assigned to the oldest, most distant objects

▲ Consider what orientation works best for your target. Traditional orientation would have the 'Cosmic Cliffs' image tilted on its side (right)

leading lines that may guide the eye towards different features? If not, can you reorient through cropping and/or rotation to make a stronger image? There is no up or down in space, and you're not obliged to adhere to the scientific standard of north = up, east = left. Of course, for well-known objects you may want to stick with the standard orientation for ease of recognition, but you be the judge of what will make your image visually strongest. I sometimes draw inspiration from Old Masters paintings or landscape photography. There's a reason these paintings and photos have withstood the test of time – they appeal to our visual instincts, and we would do well to learn their aesthetic lessons.

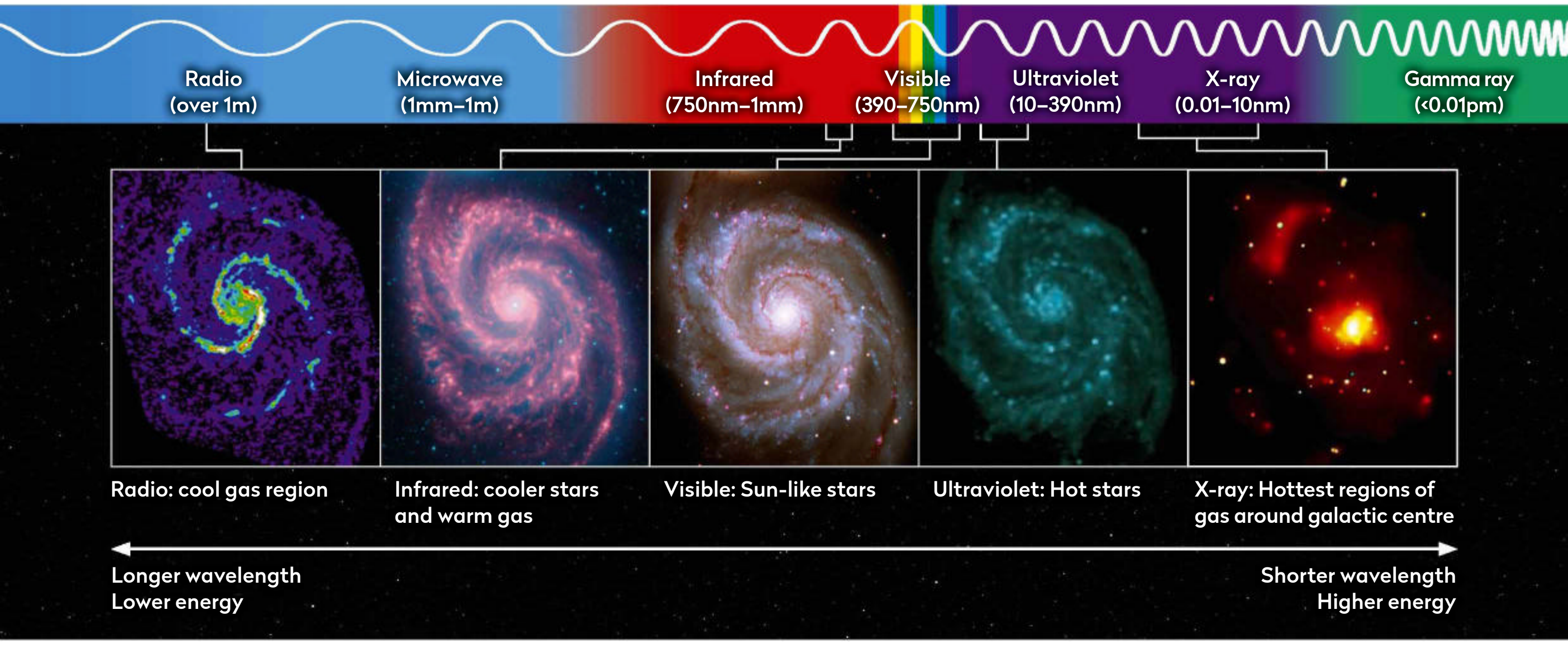
Conclusions

Our journey together ends here, but yours is just beginning! Just as explorers of the late 18th century set sail more confident than ever that they could accurately navigate the globe, I hope this has given you the guidance you need to take your own data to the next level. Despite the drastic differences in the technology of JWST versus a backyard telescope, we can apply the same principles of image processing. As 21st-century explorers of the cosmos, our oceans are the seemingly infinite pixels beamed back to us by our instruments. Navigating those pixels and finding the details buried in the darkness is our charge. Go forth and discover, and as always, clear skies!

▶ Learn from the Masters: compare and contrast, say, the tonality and composition of 30 Doradus with Caravaggio's *Judith Beheading Holofernes*

The electromagnetic spectrum

Jane Green explains what different kinds of light can reveal about our Universe



▲ **Five views of the Whirlpool Galaxy, M51 in wavelengths from radio (left) to X-ray (right), unlocking a trove of information beyond what's visible to the human eye**

When we think about light, most people only think in terms of what our eyes can see. But this 'visible' light is just a fraction of the light, or electromagnetic radiation, suffusing the cosmos. The entire range of this radiation is called the electromagnetic, or EM, spectrum.

Electromagnetic radiation is described as a stream of massless particles, called photons, travelling in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy, and different types of radiation are defined by the amount of energy found in those photons. Radio waves have low energies, microwave photons have a little more energy, infrared photons have still more. Then comes visible, ultraviolet, X-rays, and finally the most energetic of all, gamma rays.

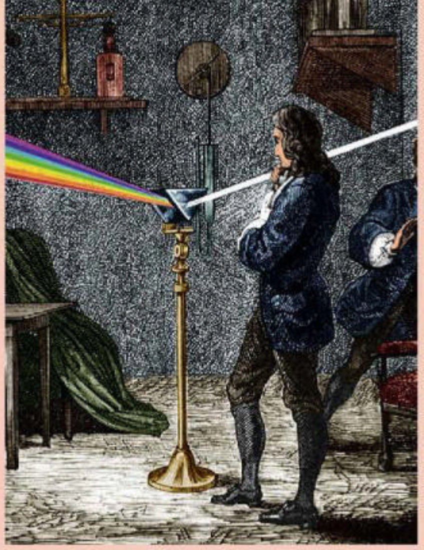
Just as ocean waves create vibrations or oscillations, light waves create 'disturbances' in space. Distinctly, they are the synchronised oscillations of magnetic and electric fields – hence the name electromagnetic.

The number of waves passing a point in one second is called the 'frequency' and is measured in hertz (Hz). The distance from the peak of one wave to the next is the 'wavelength'. These two attributes are inversely related; the larger the frequency, the smaller the wavelength, and vice versa. Electromagnetic waves all move at the speed of light no matter their wavelength, but our eyes are only able to detect visible light, which oscillates between 400 and 790 terahertz (THz). That's several hundred trillion times a second, with a wavelength the size of a large virus: 390 to 750 nanometres (1 nanometre = 1 billionth of a metre).

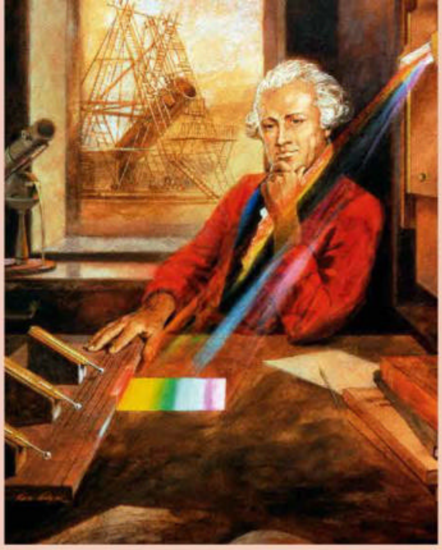
Seeing the full picture

The human brain interprets different wavelengths of visible light as colour, the longest wavelengths being red and the shortest violet. Most stars emit some of their electromagnetic energy as visible light. But just as there are sounds beyond the range of human hearing, there is light in the Universe which is invisible to our human eyes.

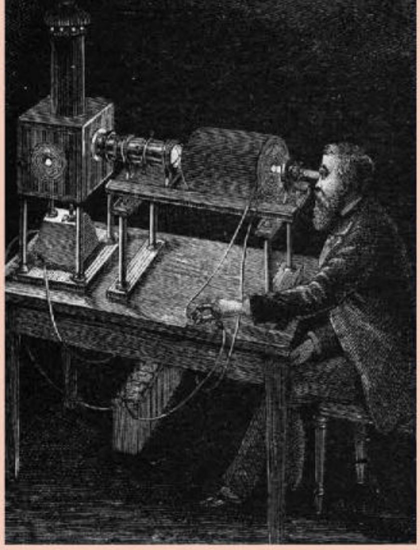
The more energetic a photon is, the faster it oscillates, and so the shorter its wavelength. Longer-wavelength radiation emanates from the cooler regions of space, while highly energetic phenomena create shorter wavelengths of radiation. This means



▲ Newton laid the foundations for modern optics with his discovery of a spectrum of colours within white light



▲ Making the connection of light with heat, Herschel discovered light beyond red (infrared) warmed thermometers the most



▲ James Clerk Maxwell made the huge conceptual leap that light in all its forms was waves of electromagnetic radiation

The history of decoding the EM spectrum

Over the centuries, the electromagnetic spectrum has been revealed piece by piece

1672 Isaac Newton used a glass prism to split white light into its constituent rainbow colours of red, orange, yellow, green, blue and violet.

1800 British astronomer William Herschel measured the temperature of each colour. A thermometer placed beyond the red light of the spectrum, where there appeared to be no visible light, was the warmest, revealing the existence of infrared light.

1801 German physicist Johann Wilhelm Ritter noticed paper soaked in silver chloride – which would later be used for photography – was darkened more by the 'invisible light' beyond violet than the colour itself, revealing the existence of ultraviolet light.

1867 Scottish scientist James Clerk Maxwell predicted the existence of light with longer wavelengths than infrared.

1887 German physicist Heinrich Rudolf Hertz demonstrated Maxwell's waves by producing radio waves in the laboratory.

1895 While experimenting with vacuum tubes, German scientist Wilhelm Conrad Rontgen detected invisible rays passing through the cardboard shields that blocked visible light. He called this radiation 'X-rays' to indicate it was unknown.

1900 French chemist and physicist Paul Villard observed radiation from radium (discovered two years earlier by the Curies). It was clear the waves were akin to X-rays but with much shorter wavelengths. The British physicist Ernest Rutherford proposed the name 'gamma rays' for this radiation.

that a star's colour can inform us how hot it is: red stars are coolest and blue the hottest (the opposite of what you're used to on hot and cold taps).

Astronomers observe the cosmos across the entire electromagnetic spectrum. By detecting low-energy, long-wavelength radio and microwaves we can study dense, cold interstellar clouds and map the structure of our Milky Way Galaxy. Exquisitely sensitive microwave telescopes are used to map the remnant glow of the Big Bang. Studying infrared waves, which transfer heat, enables astronomers to sift through drifting dust lanes that would otherwise block our view, allowing us to see our Galaxy's core, locate predominantly cool, dim stars and measure the temperature of exoplanets.

Radiation with wavelengths shorter than violet is called ultraviolet light, or UV. Astronomers use this to search for highly energetic hot blue stars and explore areas of star birth in distant galaxies. Beyond the ultraviolet are the highest energies of radiation: X-rays and gamma rays. Earth's atmosphere blocks this light, so astronomers employ orbiting telescopes to view the X-ray and gamma-ray Universe. Exotic X-ray sources such as neutron stars, superheated gas swirling around black holes and million-degree diffuse clouds lurking in galactic clusters are all visible with X-ray vision.

▲ This glimpse of our Milky Way's core, fizzing with swirling gas and dust, was only made possible in infrared gathered by three orbiting space telescopes

Jane Green is an astronomy presenter, speaker, writer and fellow of the Royal Astronomical Society

Gamma rays are the shortest wavelength of light and deadly to humans, but they expose extremely violent events, including supernovae, colliding neutron stars and cosmic radioactive decay. Indeed, the most energetic events in distant galaxies – gamma-ray bursts – are detectable with gamma-ray telescopes, providing evidence of stellar explosions and black hole births.

All these wavelengths of light, whether seen or unseen, form the electromagnetic spectrum – the toolbox used by astronomers in their exploration of space.

Practical astronomy projects for every level of expertise

DIY ASTRONOMY

Predict an aurora display

Top tips for taking the guesswork out of catching the amazing natural spectacle

◀ **Mary's photographs of the aurora taken in Oxfordshire in June 2015 (left) and February 2023 (right)**

Seeing the aurora borealis (Northern Lights) or aurora australis (Southern Lights) is at the top of many people's bucket lists, but you don't need to travel to the polar regions to see or photograph a display. Armed with forecasting data, you can be ready and waiting when the conditions are right.

On 1 September 1859, Richard Carrington and Richard Hodgson recorded the first visual observation of a solar flare. Less than 18 hours later, the largest geomagnetic storm ever recorded, the Carrington Event, began. Aurorae were seen all around the world, even in equatorial locations. It was the first definitive proof that aurorae are directly linked to solar activity.

When charged particles from the Sun, the solar wind, interact with molecules in our atmosphere, they glow. Earth's magnetic field channels the particles down towards the polar regions, which is why aurorae are usually seen within the Arctic and Antarctic Circles. Solar flares and their associated coronal mass ejections (CMEs) can send much higher-energy solar wind towards Earth, causing geomagnetic storms.

Mary McIntyre is an outreach astronomer and teacher of astrophotography

Aurorae on the rise

It's not only CMEs that cause them. Disruptions in the Sun's magnetic field can lead to 'coronal holes' that allow faster-moving solar wind to stream out from the Sun, which can lead to mid-latitude aurorae. As we are currently close to the maximum period of activity in the Sun's solar cycle, there have been a lot of mid-latitude aurora displays already this year.

Space weather is now monitored constantly and scientists are getting better at forecasting aurorae. We have satellites imaging the Sun in different wavelengths and recording solar flares and CMEs. Real-time magnetic data and geomagnetic storm predictions are published on websites, social media accounts and apps. All this information will help you to predict if there's a chance of aurorae where you are. However, the only thing you can accurately predict about aurora displays is their unpredictability!

Some websites rate the activity level using the Kp Index, with a scale of 1 to 9. The higher the number, the further south (or north) aurora can be seen. Others publish the interplanetary magnetic field data. The total value (Bt) is measured in nanoteslas, but also crucial is its polarity (Bz). If the Bz is negative (the greater the negative value the better), it shows more charged particles are pouring into our magnetosphere, causing a stronger aurora in the coming hours.

To see the aurora, you need a clear view of the northern horizon (or southern horizon if you're in the Southern Hemisphere) and to allow your eyes to dark-adapt (about 20 minutes). Visually, aurora displays are not as colourful as they are in photos, so have a realistic expectation of what you'll see. If you are at a mid-latitude location, bursts of very active aurorae may be short-lived, so be ready to act fast!

Aurora alert sites

▶ **sdo.gsfc.nasa.gov/data** The Solar Dynamics Observatory website lets you study photos of the Sun and monitor solar activity

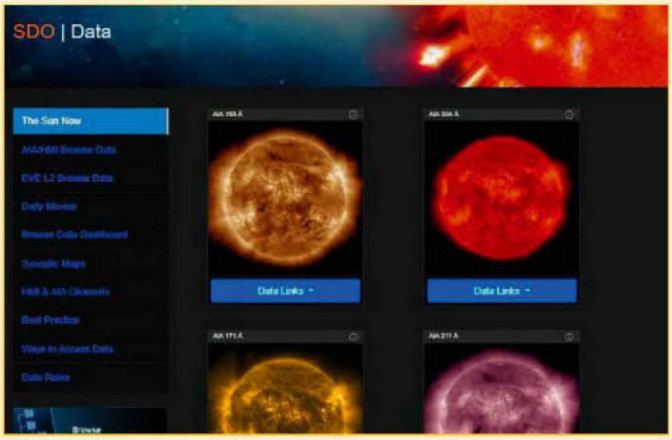
▶ **flareaware.com** gives live updates of solar flares and CMEs, as well as geomagnetic storm predictions and alerts

▶ **www.youtube.com/@TamithaSkov** Dr Tamitha Skov, aka Space Weather Woman, provides weekly space weather forecasts and one-off videos when large storms are forecast

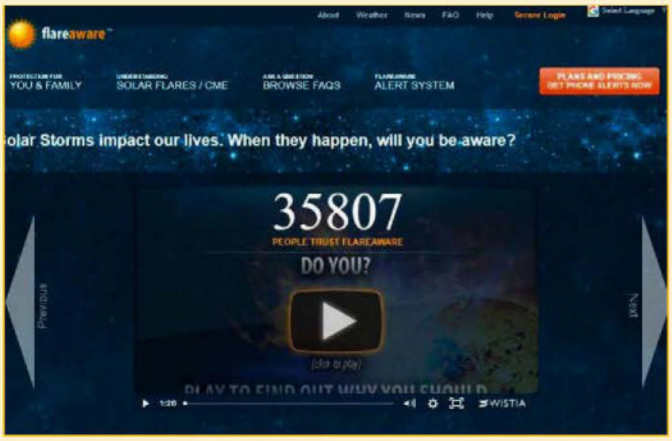
▶ **spaceweather.com** is a fantastic resource for checking auroral activity levels and 48-hour geomagnetic storm predictions

▶ **aurora-alerts.uk** This is where to download Glendale, which claims to be the most accurate aurora forecasting and alerting app in the world

Six ways to predict the aurora



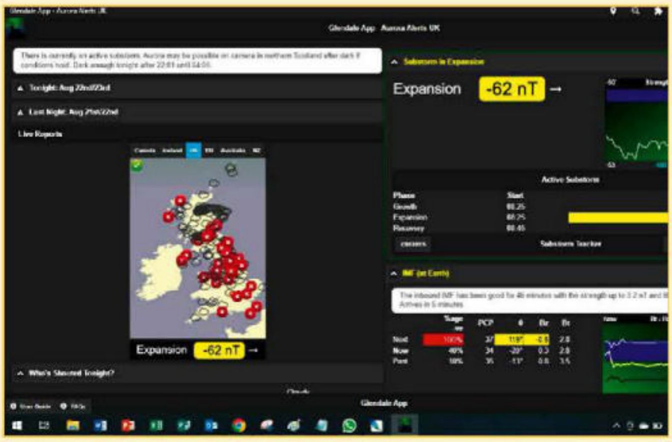
1. Visit the Solar Dynamics Observatory website and look at the daily 211 angstroms photo. Any dark regions are coronal holes. If these dark areas are in the Sun's equatorial region, faster solar wind will be Earth-directed and may result in geomagnetic storms a couple of days later.



2. Check the Flare Aware website to see how many solar flares have taken place recently and if there are any Earth-directed CMEs associated with them. Even CMEs that aren't directly heading for Earth can give us a grazing blow and bump up auroral activity.

3. Subscribe to Tamitha Skov's YouTube channel and watch her space weather forecast videos. She analyses the NOAA (National Oceanic and Atmospheric Administration) and NASA prediction models following significant CMEs and gives geomagnetic storm probabilities for high-latitude and mid-latitude regions.

4. Spaceweather.com summarises recent solar flares, coronal holes, current solar wind speed, Kp (geomagnetic activity), Bt (interplanetary magnetic field) and Bz (polarity) levels, current position of the auroral oval and probability of geomagnetic storms from high and mid latitudes in the next 48 hours.



5. Register, input your location and the Glendale Aurora Alerts App will provide geomagnetic measurements specific to your area rather than the global readings. It gives live, real-time alerts, and other app users add green ticks on a map if they have aurorae, so you can see at a glance if you're in with a chance yourself.

6. There are many aurora webcams around the world, including in Norway, Canada, Finland and the Shetlands in the UK. Studying the view from live cameras in your country allows you to monitor how active an aurora display is in real time and can help you predict whether the aurora will reach your location.

Take the perfect astrophoto with our step-by-step guide

ASTROPHOTOGRAPHY CAPTURE

Venus's vanishing act

Record the bright planet as it disappears behind the Moon on the morning of 9 November

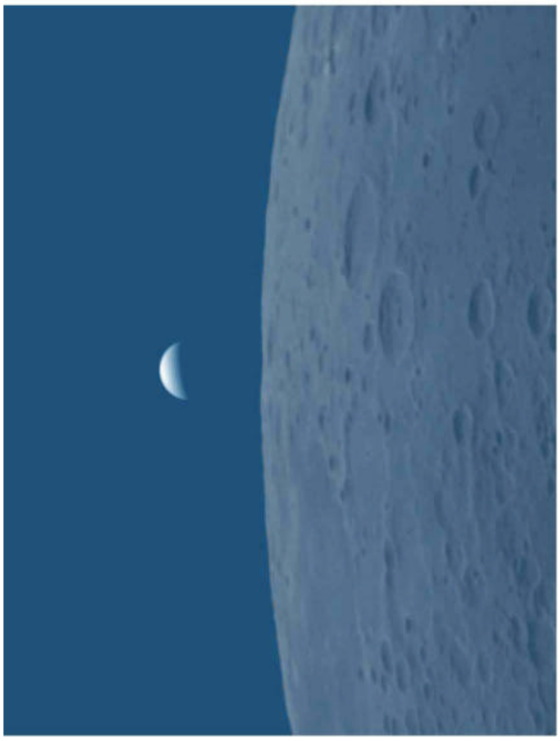
Venus will disappear behind the Moon's disc at around 09:43 UT on 9 November, during an event known as a lunar occultation of Venus. Such events are infrequent enough to make them quite special to chase and record. Here, we're looking at different methods you can use to do just that.

The occultation takes place during daylight hours, which isn't much of an issue for Venus. Currently shining at mag. −4.2, it's possible to pick the planet out of a bright blue sky with the naked eye so long as you know where to look. The Moon will be at a 15%-lit waning crescent phase on the morning of 9 November, separated from the Sun by 45 degrees.

The lunar crescent should be fairly easy to locate in daylight but to guarantee finding it, catch it before sunrise. Given clear skies and dark-sky conditions, the crescent Moon near brilliant Venus should be pretty stunning. Moonrise from the UK's centre is around 02:42 UT, Venus appearing just before 03:00 UT above the eastern horizon. The occultation occurs 2 hours 20 minutes after sunrise.

The brightness of both subjects means they can be captured with many types of cameras and lens/telescope combinations. For example, a DSLR and telephoto lens will frame the Moon and Venus in the same shot, while a high-frame-rate camera attached to a telescope can give a more magnified view.

As the Moon is moving east relative to Venus, it's the bright edge of the Moon which covers the planet. This is easy to see and it should be relatively straightforward to frame the disappearance event with a higher magnification setup. We would however, advise against an image scale that has Venus filling the frame; this would lose the impact and substance of the occultation. Covering say 20 per cent of the lunar limb in a single shot should be fine.



▲ **A crescent Venus next to the illuminated edge of the Moon prior to a lunar occultation of the planet in June 2007**

ALL PICTURES: PETE LAWRENCE

Venus will have a gibbous phase of 58% and an apparent diameter of 20 arcseconds, one-90th the Moon's apparent diameter, comparable in apparent size to the dark 46km crater Billy, which lies to the north of the disappearance point.

One surprising thing to note from the occultation is just how much brighter than the Moon Venus appears. This sets the upper level for exposure settings and may render the Moon's surface darker than you'd like. If you decide to capture the planet and Moon separately for a subsequent composition, that's fine, but do make sure this is put in the description of the final shot to avoid any future confusion.

The reappearance of Venus will be harder to deal with because the planet will appear from behind the Moon's dark edge, a boundary which won't be visible during daylight. Here, a more relaxed image scale will help to take the pressure off, albeit resulting in a smaller image of Venus. However you decide to capture the event, the rarity of a lunar occultation of a planet really makes the result worth putting in the effort for. Good luck and clear skies for 9 November.

Pete Lawrence is an expert astro-imager and a presenter on *The Sky at Night*

Equipment: DSLR or equivalent with a telephoto lens (300mm+) or high-frame-rate camera with a telescope. Tracking mount

▶ **Turn to page 46 to read more about the event**

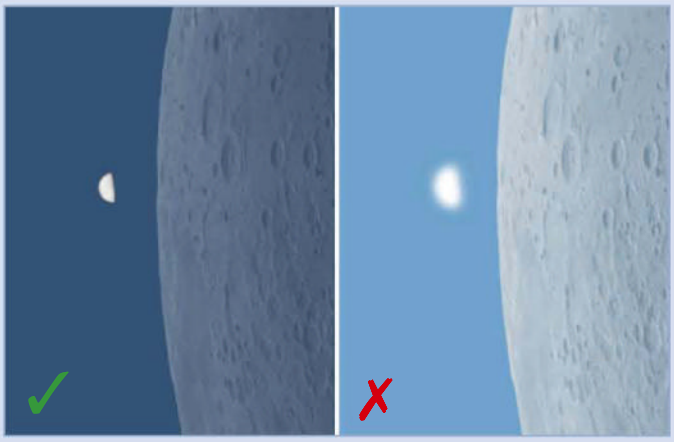
Send your images to:
gallery@skyatnightmagazine.com

Step by step

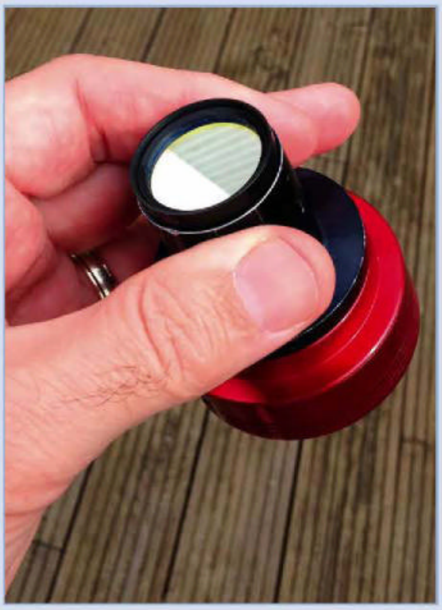
STEP 1
Decide how you'll find the Moon and Venus on the morning of 9 November. It's worth getting up before sunrise and locating both objects against a dark twilight sky. This makes for an interesting photo in its own right. If you have a tracking mount, centre on the Moon, continuing to follow it through to the occultation.

STEP 2
Plan what image scale you want for the disappearance and reappearance events. Disappearance is easier to zoom in on because you can see Venus and where the edge of the Moon will be before the event. Reappearance is much harder because you can't see Venus or the Moon's edge before the event occurs.

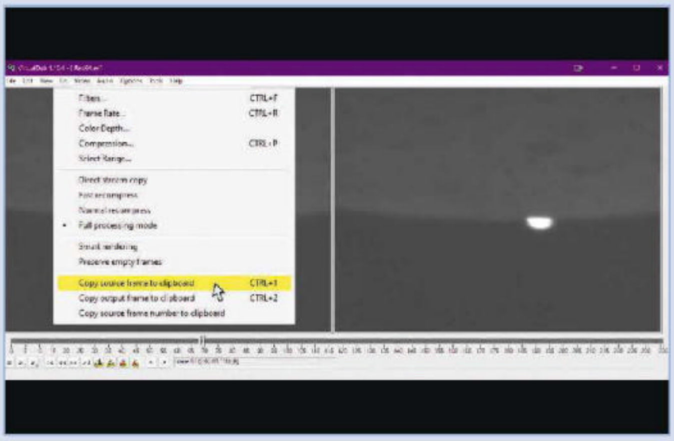
STEP 3
If you're using a DSLR or equivalent fitted to a telephoto lens or telescope, frame the Moon's edge to your preference. Aligning the Moon so its equator is parallel to your frame's long edge is helpful as both events occur south of the lunar equator. In other words, you can zoom in to cover just the lower half of the Moon.



STEP 4
A shot of the entire Moon is the safest option, but the planet will appear small. Focus on Venus, getting it as sharp as you can. If possible, grab shots at regular intervals before the event, adjusting the ISO low. With a DSLR, it's likely Venus's disc will be over-exposed, so try to avoid the planet bloating beyond its edge.



STEP 5
A high-frame-rate camera can get you in closer to the action. If you have a mono camera, consider using an IR-pass filter to darken the background sky. Adjust your exposure carefully to avoid over-exposing Venus. Low gain and short exposures should allow you to keep your capture sequences down to a preferable length; ideally they'll be just a few seconds.



STEP 6
At the point of occultation, keep exposures very short to freeze the action. Consider recording the event as a high-frame-rate video. Extract still frames via a movie player or utility such as VirtualDub (**virtualdub.org**). However you display your final results, include all the capture details on the image.

Bring hydrogen-alpha Sun images to life

How to sharpen, brighten and add colour to your solar photos

▲ **Before: Dave's original stacked hydrogen-alpha image of an active region of the Sun's chromosphere. After: the final version after processing with AstroSurface and Affinity Photo to sharpen it, brighten the huge filament and prominences, and introduce vibrant colour**

When using a hydrogen-alpha (Hα) telescope or filter, we view a layer above the Sun's white-light photosphere called the chromosphere. The features that are revealed in Hα, like sunspots, prominences and filaments, can be very active, often changing extremely quickly. The Sun becomes a living, breathing and very exciting star, and is amazing to watch and image in fantastic detail. It's important to emphasise that, of course, any observing or imaging of the Sun should always be done with the correct safety filters in place.

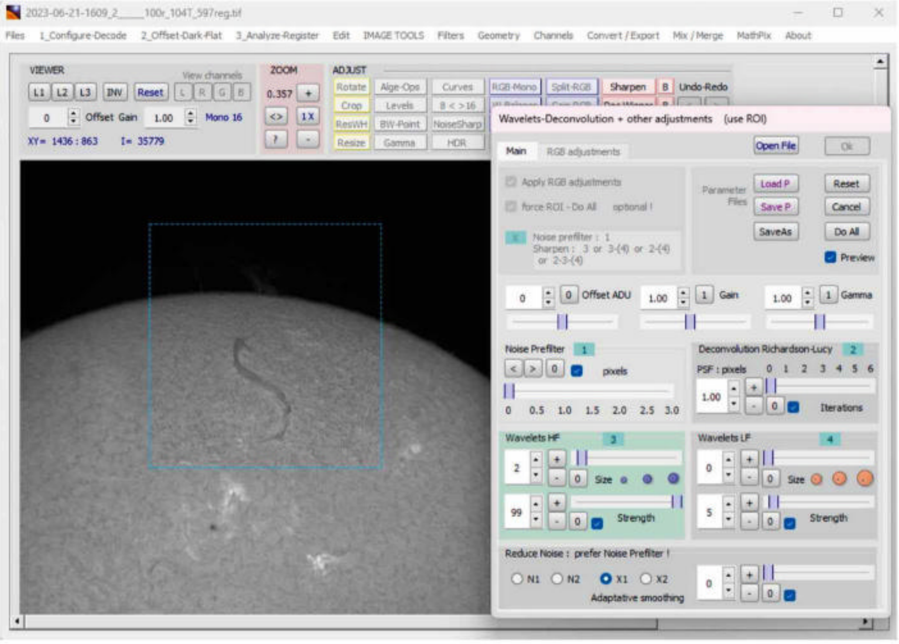
Taking images of the Sun is akin to planetary imaging. A camera, using video-capture software, captures a video composed of hundreds of individual frames. This is stacked using video-stacking software (AutoStakkert!, RegiStax or AstroSurface, for example) to produce a single image. The resulting combined image contains much less noise and has enhanced subtle detail, but this does need to be teased out using a combination of tools in AstroSurface and Affinity Photo. I'm going to take you through the processes involved.

Sharpen up

Our first step is to quickly pre-sharpen the image to reveal additional fine detail. Open AstroSurface and load your stacked image from the folder you saved it in. Once opened, select 'Filters' › 'Wavelets-Deconvolution' from the menu (see Screenshot 1). If 'Use (ROI)' is displayed at the top right of the tool window that pops up, using the mouse draw a square around a part of your image to see the effect as the tool is adjusted. The tool remembers the last setting used. Click 'Reset' to start afresh.

Start with the top 'Wavelets HF' slider (labelled in the program as '3'), moving it a small amount to the right. A small adjustment gives a nice sharpening to the image, but if noise appears move the bottom 'Wavelets HF' slider slightly to the left. If more noise reduction is needed, the 'Noise Prefilter' slider (labelled '1') can be moved to the right. Once you're happy with the result, click 'Do All' (if ROI was used), then 'Ok'. Don't be afraid to repeat this step, resetting the tool and using smaller adjustments if required. Save this image using a different name so that the original image is not overwritten.

ALL PICTURES: DAVE EAGLE



▲ **Screenshot 1: In AstroSurface, adjust the 'Wavelet Deconvolution' options to sharpen your image, taking care to keep noise under control. Once you're happy, click 'Do All'**

3 QUICK TIPS

1. 'Wavelets LF' and 'Deconvolution Richardson-Lucy' adjustments in AstroSurface can be used to further improve the sharpness in good-quality images.

2. Treat sharpening with caution. Over-sharpening causes unwanted artefacts. Small, gentle adjustments are always best.

3. Save your workflow as an adjustment preset or a macro to perform elaborate changes with just a single click.

Next we turn to Affinity Photo. Open your pre-sharpened image. In my image, prominences could be seen at the top limb, but they were quite faint. To brighten features like this, select 'Layer' › 'New Live Filter Layer' › 'Shadows/Highlights' (see Screenshot 2). Slide the top two sliders differing amounts to the right to brighten the prominences, then click 'Merge'.

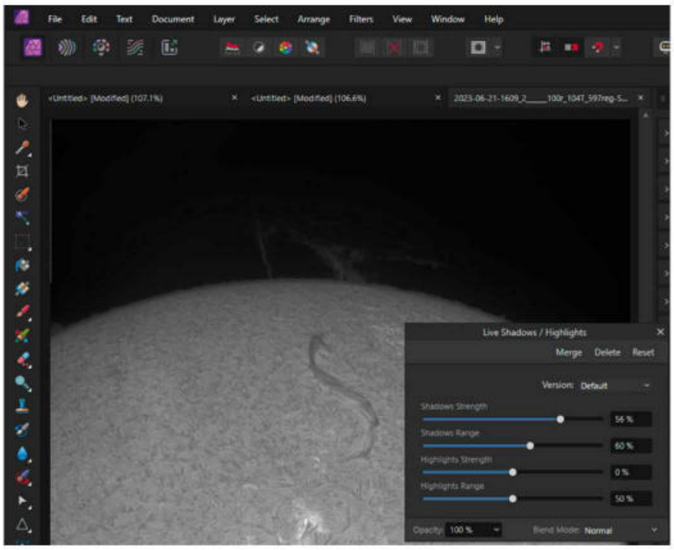
Now we can apply a little more sharpening to the image using 'Live Filter Layer'. Click 'Layer' › 'New Live Filter Layer' › 'Sharpen' › 'Clarity'. Move the slider to the right to apply gentle sharpening. Continue until you're happy with the adjustment, then click 'Merge' to finish the process.

Although the Sun is white, everyone loves to see images of the Sun as orange, so next we add some colour to the image. First we need to check and possibly change the document type. Select 'Document' › 'Convert Format/ICC Profile'. The image type should be 'RGB/16'. If the image file is a different format, select 'RGB/16' from the dropdown menu and click 'Convert'.

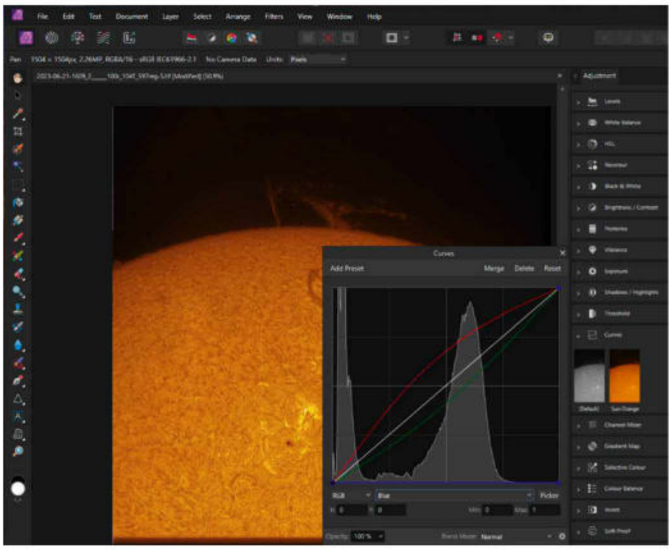
Now open the 'Curves' adjustment tool. In the window that opens (shown in Screenshot 3), below the histogram where it says 'Master', select 'Blue' from the dropdown list. Grab the middle of the blue line on the histogram and drag it as far down to the bottom right-hand side of the histogram as possible. Then select 'Red' from the dropdown list and slightly drag the red line up, making a gentle curve above the diagonal white line. Switching to 'Green', drag the line to curve slightly below the white line. The Sun should now be orange. Click 'Merge'.

Finally, use the crop tool to cut out the edges of the image to remove stacking artefacts, then save the file as a new image ('File' › 'Export'). On the page opposite you can see how my final processed image turned out.

Dave Eagle is an astronomer, astrophotographer, planetarium operator and writer



▲ **Screenshot 2: In Affinity Photo, use 'New Live Filter Layer' to brighten features like prominences before sharpening a little more**



▲ **Screenshot 3: Finally, turn your Sun a vibrant orange by adjusting the blue, red and green channels in Affinity Photo's histogram**

Your best photos submitted to the magazine this month

ASTROPHOTOGRAPHY GALLERY

More **ONLINE**
A gallery containing these and more of your images

PHOTO OF THE MONTH

△ The Lagoon and Trifid Nebulae

Antoine and Dalia Grelin, captured remotely via Utah Desert Remote Observatories, Utah, USA, 1–2 August 2023

Antoine and Dalia say: "This shows a widefield view that includes both objects in the same frame. A large amount of nebulosity is visible even without the use of any filters, thanks to a very fast telescope (f/2) and dark skies (Bortle 2)."

Equipment: ZWO ASI2600MC Pro camera, Celestron 8-inch Rowe-Ackermann Schmidt astrograph, 10Micron GM1000 HPS mount
Exposure: 96x 300", 8h total
Software: PixInsight

Antoine and Dalia's top tips: "Fitting two nebulae in the same frame is both exciting and challenging for beginners. To achieve something like this, use a scope with a wide enough field of view, usually with a focal length under 400mm. Plan your framing in a program like Stellarium or SkySafari, and ensure the angle of your camera matches what you expect your final result to look like! During processing, look at both objects after each step to achieve similar brightness levels, colours and details on both."

Comet Nishimura ▷

Osama Fathi, Black Desert, Egypt, 26 August 2023

Osama says: "Comet C/2023 P1 (Nishimura) wasn't visible with the naked eye, but I got up an hour before dawn and managed to capture it with a telescope."

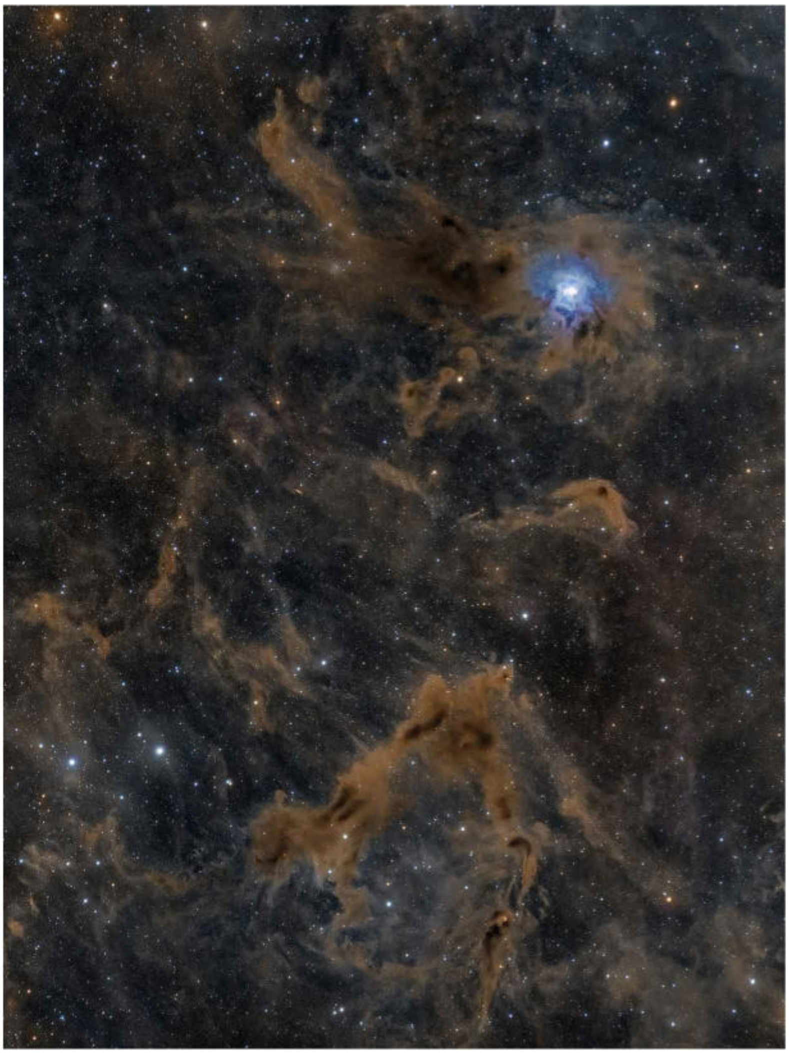
Equipment: ZWO ASI294MM Pro camera (comet), Nikon Z6 mirrorless camera (foreground), William Optics RedCat 51 refractor, Sky-Watcher Star Adventurer 2i mount **Exposure:** ISO 800 19x 1', ISO 10,000 26x 30" (comet); ISO 1,000 3x 2.5" (foreground) **Software:** DeepSkyStacker, PixInsight, Photoshop

▽ Blue supermoon

Shreya Roy, Kolkata, India, 30 August 2023

Shreya says: "I went to our rooftop and captured two different exposures, then used Snapseed to stack those two images to achieve a captivating HDR glow in the final image."

Equipment: Nikon D5600 DSLR camera, Nikon 70–300mm lens, Digitek tripod
Exposure: ISO 800 f/6.3, 1/4", ISO 800 f/6.3, 1/320"
Software: Snapseed, Lightroom



The Iris Nebula ▷

Harshwardhan Pathak, remotely via Telescope Live, IC Astronomy Observatory, Spain, 11–13 August 2023

Harshwardhan says: "The key was long integration and using curves adjustments to reveal the hidden dust behind the stars."

Equipment: QHYCCD QHY600 Pro camera, Takashi FSQ-106EDX4 refractor, Paramount MX+ mount **Exposure:** L 15x 300", R 15x 300", G 15x 300", B 15x 300" **Software:** PixInsight, Photoshop

△ LDN43, the Cosmic Bat Nebula

Daniel Stern, remotely via Deep Sky Chile, Rio Hurtado, Chile, 12–13 August 2023

Daniel says: "The small galaxy seen below LDN43, just to the left of a bright orange star, is LEDA 3868080. This galaxy is located 400 million lightyears away and is slightly larger than our Milky Way."

Equipment: Moravian C4-16000C camera, PlaneWave CDK17 astrograph, PlaneWave L-500 mount
Exposure: L 47x 300", R 17x 300", G 16x 300", B 15x 300"
Software: PixInsight

▽ Phases of Venus

Roberto Ortu, Cabras, Sardinia, Italy, 23 May–8 August 2023

Roberto says: "This shows the different phases of Venus and the increase in its apparent diameter as it comes closer to Earth. It wasn't easy to get good photos due to the proximity of the planet to the horizon. I had to take the last shots in broad daylight."

Equipment: QHYCCD QHY5L-II camera, Celestron PowerSeeker 114EQ Newtonian, Celestron CGEM II EQ mount
Exposure: 7 videos, 0.2330ms–0.9867ms
Software: PIPP, AutoStakkert!, AstroSurface, GIMP

△ NGC 908

Warren Keller, remotely via SC Observatory, El Sauce Observatory, Chile, 14–15 December 2022

Warren says: "I'm very grateful to Mike Selby at SC Observatory for his help in capturing what may be the definitive amateur version of rarely imaged NGC 908."

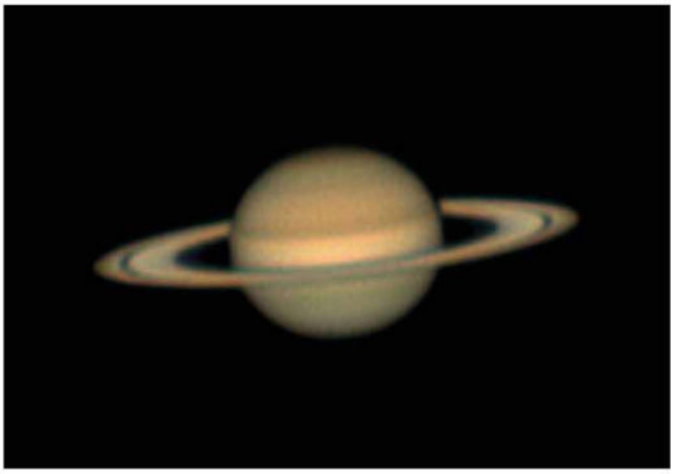
Equipment: QHYCCD QHY461PH camera, PlaneWave CDK1000 astrograph (luminance); ProLine PL16803 camera, PlaneWave CDK700 astrograph (RGB) **Exposure:** L 9.5h, R 4.5h, G 4.5h, B 4.5h **Software:** PixInsight

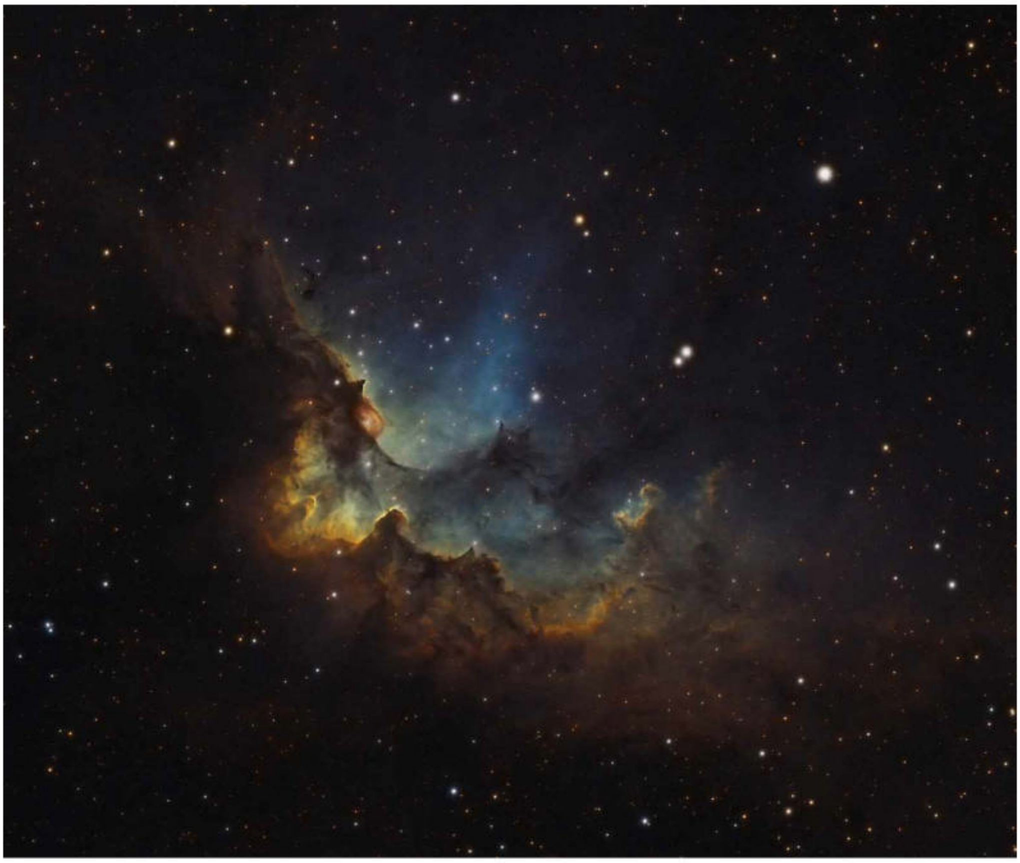
▽ Saturn

Robbie Smith, Stevenage, Hertfordshire, 15 August 2023

Robbie says: "Saturn was due to be at opposition on 26–27 August but, not trusting the UK weather, I took this shot on 15 August. You can see the rings are closing up now. In March 2025 they will disappear completely when we see them edge-on."

Equipment: ZWO ASI178MC camera, Celestron C9.25 XLT Schmidt-Cassegrain, Sky-Watcher EQ6-R Pro mount **Exposure:** 5,000x 30ms **Software:** PIPP, AutoStakkert!, RegiStax, GIMP





◁ The Wizard Nebula

Leticia Theobald, Stevenage, Hertfordshire, 29 July–8 August 2023

Leticia says: "I've been doing astrophotography for eight months now and this is the first image that I took using a monochrome camera. This was quite a faint target and I wanted to really test the camera. It wasn't the easiest with the UK weather and lack of dark nights in the summer."

Equipment: ZWO ASI2600MM Pro camera, William Optics Zenithstar 73 III refractor, Sky-Watcher HEQ5 Pro mount **Exposure:** Ha 60x 300", OIII 40x 300", SII 56x 300" **Software:** PixInsight, Lightroom

ENTER YOUR IMAGE

Whether you're a seasoned astrophotographer or a beginner just starting out, we'd love to see your images. Send them to us at www.skyatnightmagazine.com/send-us-your-astrophotos

The best in equipment, accessories and books each month

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90

Seeing red: its looks will certainly turn heads, but how does the striking RedCat 61 WIFD perform?

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PLUS: latest astro gadgets and books on women in STEM, awe-inspiring space facts, eclipses and more

HOW WE RATE

Each product we review is rated for performance in five categories. Here's what the ratings mean:

★★★★★ Outstanding ★★★★★ Very good
★★★★★ Good ★★★★★ Average ★★★★★ Poor/avoid

First Light Optics
Remote Observatory package

For a monthly fee, capture your astro images under immaculate dark skies

WORDS: TIM JARDINE

VITAL STATS

- **Price** From £349/month
- **Minimum subscription** 1 month
- **Optics** StellaMira 90mm triplet refractor
- **Camera** ZWO ASI2600 colour or mono
- **Software** Sequence Generator Pro
- **Supplier** First Light Optics
- **Email** contact@remoteobservatory.com
- **www.**remoteobservatory.com

Rather than a piece of astronomy equipment, this month we're reviewing the new Remote Observatory package from First Light Optics (FLO), which offers subscribers the chance to directly control an observatory and take their own astrophotos using familiar software and equipment that is typical of a decent home setup.

The observatory itself is situated in Granada, southern Spain, within the excellent PixelSkies complex. Although sited in the middle of nowhere, with superb crystal-clear skies unblighted by light pollution, accessing the Windows mini PC that controls the setup installed there is remarkably efficient and we could operate the system in close to real time via our laptop or the handy phone app.

Our chance to review FLO's Remote Observatory coincided with a particularly dreary spell of cloudy and wet weather in the UK, and it was with a certain smugness that we remotely accessed the observatory each night, set our assigned rig to work and then settled down to watch the results rolling in while the rain at home rattled on the windows. The luxury of repeated clear, dark nights is something to savour, and they enabled us to concentrate on imaging impressive deep-sky objects that have been elusive or even impossible from home, namely the Trifid and Lagoon Nebulae, the Eagle Nebula with the famous Pillars of Creation, and our personal bucket list target, the Helix Nebula.

Logging in

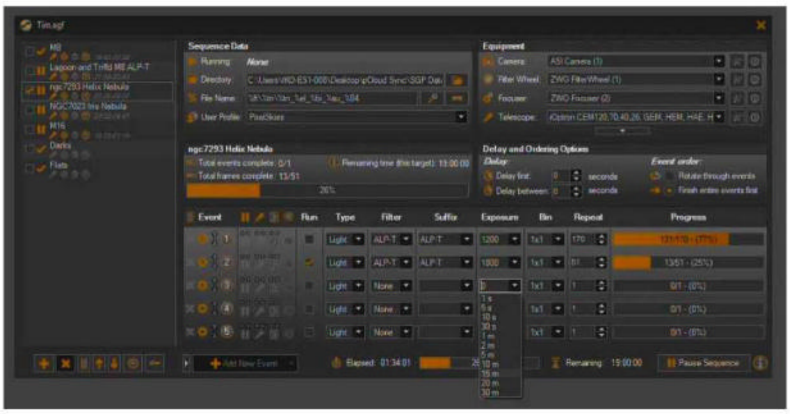
A typical session starts with logging in and checking the local weather reports on **www.remoteobservatory.com**, which is updated every few minutes, along with a feed from an all-sky camera. The enchanting sight of the Milky Way arching overhead on this camera really whets your appetite to get the cameras running. The observatory roof is opened or closed automatically; if it's open, the conditions are right for astronomy. There are just two apps that are used, the main one being Sequence Generator Pro. This gives almost total control of the observatory ▶

You're in control

Nowadays you can download image data even from Hubble or the JWST, or pay for time on, and take images with, telescopes around the world. The difference with FLO's Remote Observatory is that you get true and total control over what the telescope and camera does. From choosing the session start time, selecting the target and framing to your tastes, setting an appropriate filter and exposure duration, to gathering calibration frames, everything can be tuned to suit individual preferences.

With total control of what the telescope did, a cheeky Messier or NGC marathon, flitting from target to target getting dozens of snapshots from a deep-sky tour, was entirely possible, but we decided to stick to our plan to capture three targets.

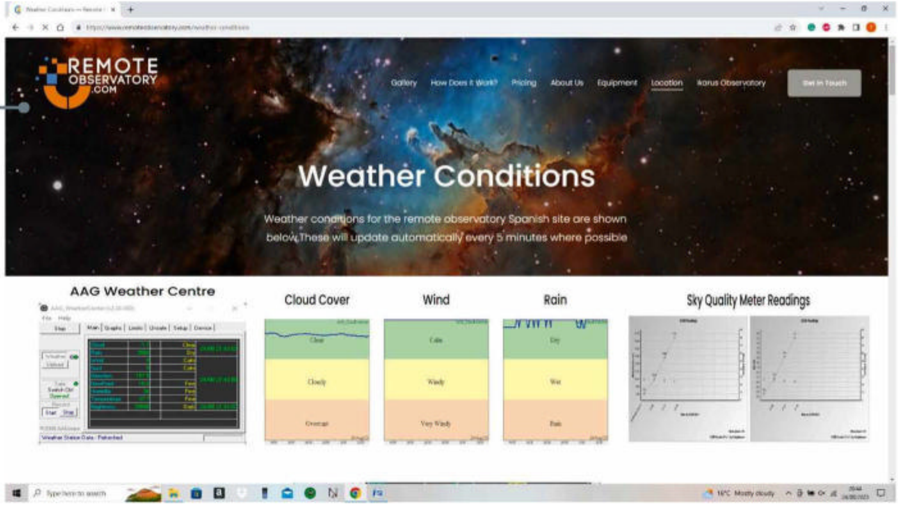
The resulting images really feel like they belong to you, that they are all your own work. Despite the Remote Observatory being a thousand miles away, using it felt just as personal as the one at the end of our garden.

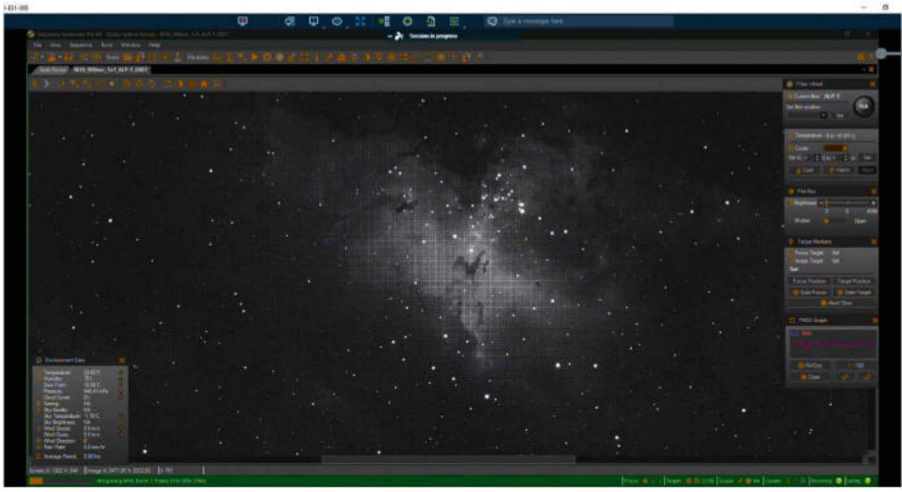


FIRST LIGHT OPTICS/WWW.REMOTE OBSERVATORY.COM X 5

Live sky-quality reports

FLO's website **www.remoteobservatory.com** gives comprehensive indicators about local sky conditions, including sky-quality meter readings, cloud cover, wind levels, and Moon phase and elevation. Updated every few minutes, there is ample data to allow for sensible target choices to be made, ensuring maximum use of the facility is achieved during your subscription.



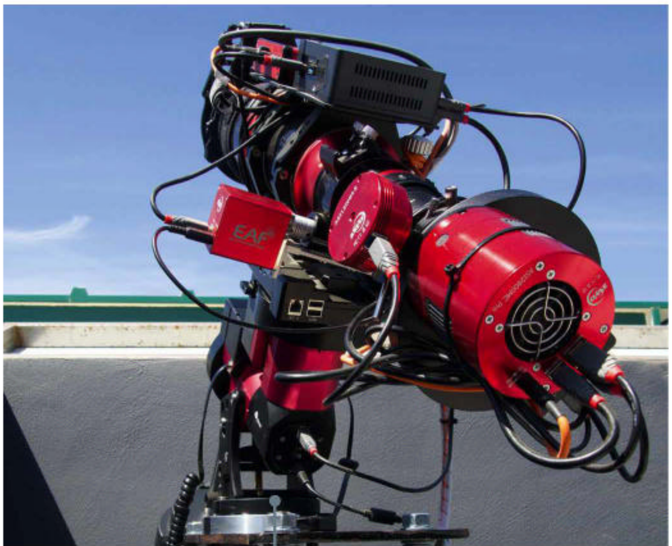


Desktop software

The Splashtop for Business remote desktop software and the accompanying phone app proved to be a reliable and stable connection between our home laptop and the control computer in Spain. After the initial security protocols, subsequent links were quickly established with just a click, allowing real-time operation of the remote equipment.

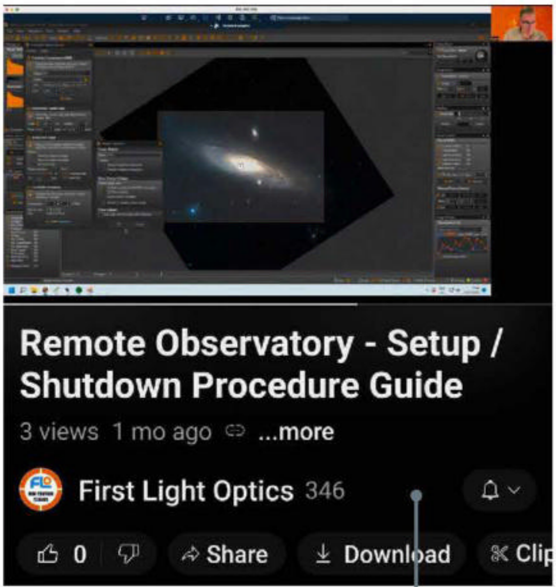
Observatory location

The observatory is nestled 850 metres above sea level in a rural spot in the Andalucian countryside in southern Spain, five kilometres from the nearest village of Castilléjar. The site latitude of 37.72°N makes it possible to photograph targets that may be too low in the sky from the UK, and astronomical darkness is maintained throughout summer.



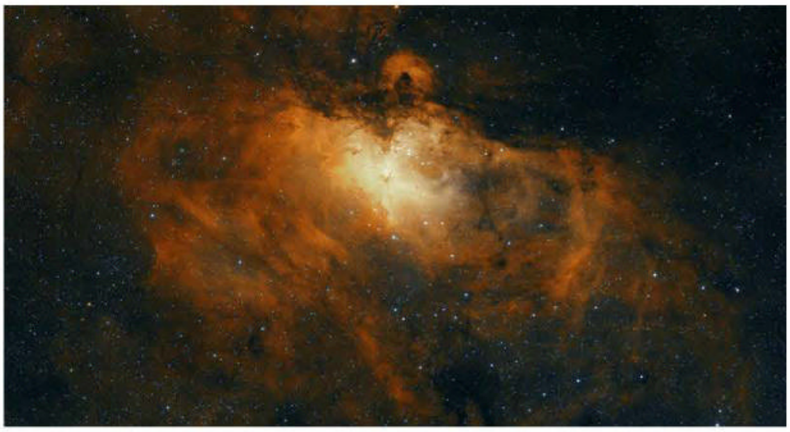
Equipment

Our setup consisted of a StellaMira 90mm refractor, iOptron CEM40 mount and ZWO ASI2600 colour camera with filter wheel. A mono camera option is available. Each telescope is fitted with a flip-flat device to keep the optics clean and create flat calibration files. FLO's approach of offering a typical hobbyist's equipment rather than high-end, very expensive gear helps to keep the subscription costs within affordable limits.



Ongoing support

Seasoned astronomers know only too well that sometimes you just get nights with gremlins in the equipment that can be hard to diagnose. When we experienced an issue we could not resolve, a mechanical failure of the mount, the FLO support system sprang into action, sorting the problem quickly and without fuss.



▶ and the equipment, including the cameras, the auto-guiding, auto-focusing, filter wheel, and so on. We were unfamiliar with some of these automatic aspects, but appreciated the patient way we were taught how to operate them.

Our initial familiarisation session via Zoom was clear and instructive, and FLO provided a user video that we could refer back to as needed. In fact, the support we received was outstanding. This initial hand-holding was invaluable and the flexible approach to installing a subscriber's preferred software, or even favourite filters, gives the Remote Observatory a welcome personal touch that further highlights the fact that the user is in control. We were impressed by the thoroughness with which FLO has undertaken this venture. Each query and theoretical issue we raised had already been considered and systems put in place to deal with them.

While it was really interesting to monitor the system as it operated and to watch the exposures downloading, there was no requirement to do so. In fact, many times after starting the imaging sequence we logged off and went to bed, secure in the knowledge that the equipment would automatically park up and close down when the session finished.

The actual image files that are captured are stored in a folder linked to a cloud-based server, so we could download them at leisure and process them on our own machine. When the stacked pictures came to life, the real value of the Remote Observatory became readily apparent. They were simply breathtaking, full of depth and detail, top-drawer images we could never capture from home.

For keen astrophotographers unable to fully enjoy the skies they have, due to overbearing light pollution, a lack of astronomical darkness or simply underwhelming weather, FLO's Remote Observatory offers the chance to take your own photos, your own way, under some of the most favourable sky conditions in Europe.

VERDICT

Package design and application	★★★★★
Ease of use	★★★★☆
Support and interaction	★★★★★
Location sky quality	★★★★★
Optics and cameras	★★★★★
OVERALL	★★★★★

▲ Top: A beautifully deep and detailed Lagoon Nebula from 16 hours of 10-minute exposures

Middle: fulfilling a lifelong ambition – the Helix Nebula from 40 hours' worth of 20-minute exposures

Bottom: one of the "top-drawer images we could never capture from home", the Eagle Nebula from 18 hours of 15- and 20-minute exposures

FIRSTLIGHT OPTICS/YOUTUBE, TIM JARDINE X 3

William Optics RedCat 61 WIFD Petzval apo refractor

The popular, powerful and compact astrograph now comes with an internal focuser

WORDS: PAUL MONEY

VITAL STATS

- Price £1,629
- Optics Petzval design
- Aperture 61mm
- Focal length 300mm, f/4.9
- Tube length 365mm
- Focuser Dual-speed WIFD
- Extras RedCat tube rings, Vixen dovetail bar, saddle handle bar, integrated Bahtinov mask, soft carry case, hex tools
- Weight 2.5kg
- Supplier The Widescreen Centre
- Tel 01353 776199
- www.widescreen-centre.co.uk

William Optics specialises in producing high-quality refractors that push technology and design whenever they can, and the RedCat 61 WIFD is no exception. It's aimed at astrophotographers and is finished in a stunning metallic red that really sets it apart. But it doesn't just look good, it's functional and, as we found, does the job very well. It is the mid-sized instrument in the RedCat range, which also includes the RedCat 51 and 71 astrographs – although these don't have the WIFD focuser design.

The RedCat 61 WIFD has a 61mm-diameter objective lens with the unique Petzval design used in William Optics's RedCat astrographs, the optical elements featuring FPL-53 glass. This provides a flat field of view along with excellent colour correction. The focal length is compact at just 300mm, giving a focal ratio of f/4.9, nice and fast, and ideal for an astrograph – and all this in a tube just 365mm long and weighing little more than a couple of bags of sugar, 2.5kg. We'll discuss the internal focuser design separately, but its placement changes the look of the refractor and marks it out from the competition.

The setup includes a dual-speed focus mechanism with a protective screw-on cap for the fine-focus knob, an integrated thermometer on the opposite coarse-focus knob, a dew shield with an integrated Bahtinov mask set in its cap, a hidden tilt mechanism and an M48 camera adaptor at the back.

User-friendly features

The RedCat 61 WIFD also comes with tube rings and a Vixen-style dovetail base, which are lighter than standard setups yet still rigid, along with a 'cat face' saddle handle bar at the top for attaching a guidescope. The tube rings also feature screw holes for attaching a finderscope. Spare screws and a set of hex keys are thoughtfully included. The keys allow adjustment of the focus tensioning and tilt mechanism, and are used to attach the optional ZWO electronic automatic focuser.

You can either mount the astrograph on a Vixen-style mount or on certain portable astro camera ▶

WIFD internal focuser

WIFD stands for William Optics Internal Focus Design. Instead of placing the focuser at the rear of the tube, in this design the focuser is internal and moves the optical assembly. Rotating the focuser knob moves the optical setup inside to achieve focus. It is roughly in the centre of the tube, which also aids in balancing the setup while your camera gear is attached to the rear of the telescope. This arrangement eliminates potential tilting due to the weight of camera gear that can sometimes occur on traditional focusers.

A window on one side shows a graduated scale so you can note the position of sharpest focus for later sessions. We found the focusing very smooth, with no slippage. The focusing mechanism is dual-speed, with coarse- and fine-focus on one side, while the main focuser knob has an integrated thermometer – useful for those with thermoelectric cooling systems on their cameras, so they can adjust them to the ambient temperature setting of the astrograph.

ALL PICS: @THESHED/PHOTOSTUDIO

SCALE

Dew shield with Bahtinov mask

The dew shield is fixed in place but provides good protection for the internal lens arrangement. The front dust cap also incorporates a detachable Bahtinov mask for focusing. Unscrew the dust cap to leave the Bahtinov mask in place, then screw back on and slide the cap off to begin imaging.

Camera adjustment, tilt mechanism and camera adaptor

The rear of the system looks odd without a traditional focuser but has several useful functions. There is the rotatable camera adjuster so you can frame your target with ease, an M48 camera adaptor that is threaded to take 2-inch filters, and a hidden tilt adaptor behind the graduated scale.

Optics

The RedCat 61's optics comprise of a 61mm-objective four-element Petzval design composed of EPL-53 glass to give a pin-sharp, flat field. The result is a 45mm image circle which allows full use of full-frame cameras, be they DSLR, mirrorless, CCD or CMOS.

Tube rings, mounting bar and saddle

The tube mounting rings, Vixen-style mounting bar and upper saddle handle bar are lightweight yet strong and rigid enough to carry the telescope. The tube rings have additional screw holes for adding a finderscope and the saddle bar allows for the firm attachment of a suitable guidescope.

FIRST LIGHT

Soft carry case

The RedCat 61 WIFD comes with a stylish, well-padded, soft carry case that protects the telescope when not in use or for travelling. There is also a package of spare screws for affixing a finderscope and a seven-piece hex key set for making adjustments to the telescope.

KIT TO ADD

1. William Optics 48mm T-adaptor for Canon/Nikon

2. William Optics 32mm slide-base Uniguide guidescope

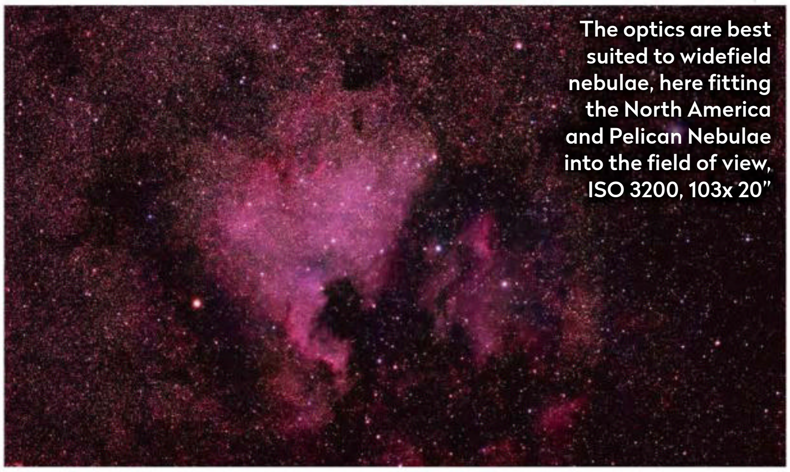
3. ZWO 5V EAF (electronic automatic focuser)

▶ tracking mounts via the threaded screw holes under the Vixen bar. If you go down this route, ensure the mount can take the weight, including that of any camera gear. You may need additional counterweights to achieve balance.

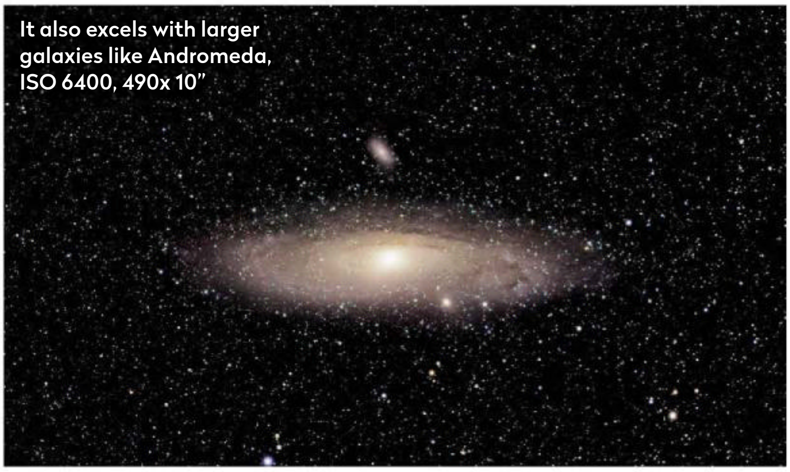
When we mounted the RedCat 61 on our Sky-Watcher AZ-EQ6 mount we did notice the focuser wheels just caught the mount. Traditionally, the focuser would be at the rear end of the telescope, so being set at the middle may cause you a slight issue. You can remedy this by either rotating the tube so that the tube assembly is in effect upside down (note this also means the graduated scale is also upside down) or add an additional Vixen bar to the base. In our case, the setup happened to balance with the focus knobs just overhanging the mount and we had no problem with this arrangement.

We borrowed the correct adaptor for our Canon R6 mirrorless camera and easily focused using the Bahtinov mask. We found the wide field of view meant we could easily fit the North America Nebula and Pelican Nebula in the same field of view with space to spare. On the few clear nights we had we also imaged the Sadr region of Cygnus, and the Andromeda Galaxy and its companions. Even with high ISO and short exposures of between 10 and 30 seconds we achieved impressive results for all three targets. We just wish we'd had more clear nights to image the star fields of the Milky Way.

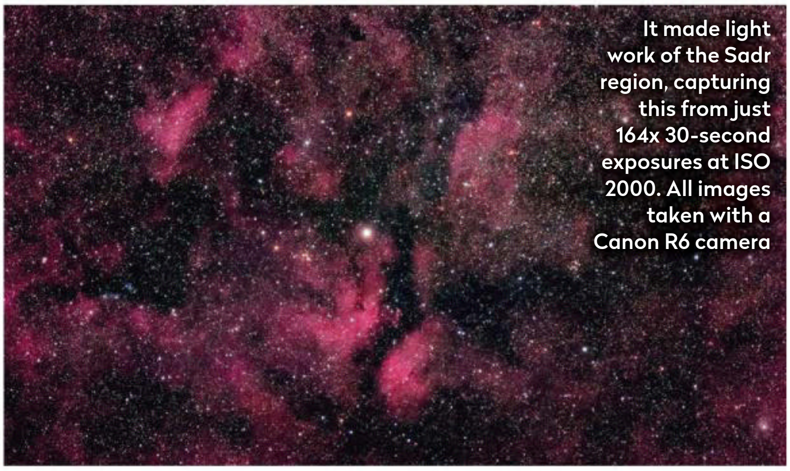
Overall, we were highly impressed with the RedCat 61 WIFD and it would make a fine addition to anyone's imaging setup. We didn't want to let it go!



The optics are best suited to widefield nebulae, here fitting the North America and Pelican Nebulae into the field of view, ISO 3200, 103x 20"



It also excels with larger galaxies like Andromeda, ISO 6400, 490x 10"



It made light work of the Sadr region, capturing this from just 164x 30-second exposures at ISO 2000. All images taken with a Canon R6 camera

VERDICT

Build & design	★★★★☆
Ease of use	★★★★☆
Features	★★★★★
Imaging quality	★★★★★
Optics	★★★★★
OVERALL	★★★★★

BOOKS

Her Space, Her Time

Shohini Ghose
MIT Press
£27 ● HB

How many women scientists can you name? A 2017 US study showed that less than one per cent of people surveyed could name a living woman scientist. Have you sat in a lecture and been greeted with 'good morning, gentlemen', despite there being women in the audience? Sad, but unsurprising. That's why we need books like Shohini Ghose's *Her Space, Her Time*.

This book shines a light on all the women scientists that history and (in most cases) Nobel committees have overlooked. There are some familiar names like Marie Curie and Vera Rubin, but have you heard of Cecilia Payne-Gaposchkin, Lise Meitner or Bibha Chowdhuri? Payne-Gaposchkin determined the chemical composition of the Universe, Meitner nuclear fission and Chowdhuri's work paved the way for the discovery of two fundamental particles.

This book is not a biography. Instead, the seven chapters are centred around physical themes, such as radioactivity, for example, and the author explores the lives and scientific discoveries these amazing women made. A chapter often jumps between the lives of the different women being discussed, in chronological order, to show how they are oddly linked. At times this can be a little confusing, but it does not detract from the content. The author nicely puts into context the importance of the problems these women solved, their influences and the barriers they faced, while including just enough physics and astronomy. For those who want to learn more about these women, the author's resources are highlighted.

This book is truly for everyone, and I can't overstate how much I enjoyed it. Women need to know that they can make the next big scientific discovery while still being true to themselves. "Rather than fixing women, what if we could fix the physics and astronomy box" instead? Representation matters.

So, learn about Marietta Blau, Chien-Shiung Wu, Harriet Brooks and many more, who were rule-breakers and trend-setters. Be warmed by their passion and be angry at why they are not celebrated in the same way as their male peers. Their stories are important to tell, so future women scientists can stand on their shoulders. ★★★★★

***Laura Nuttall** is a Future Leaders fellow at the University of Portsmouth*


ULLSTEIN BILD/GETTY

Discoverer of nuclear fission Lise Meitner, one of the overlooked figures Ghose celebrates

Interview with the author
Shohini Ghose

Which astronomers have had a big influence on you?

As a quantum physicist I am a huge fan of Cecilia Payne-Gaposchkin, who used the laws of quantum physics to discover the chemical composition of stars and was also the first woman to become chair of any department at Harvard. I also greatly admire Dilhan Eryurt, a Turkish scientist who played an important role in NASA's Apollo programme.

Are things getting better for women in STEM subjects (science, technology, engineering and mathematics)?

We've come a long way as a society, but have some way to go. What gives me hope is that we are moving away from just trying to improve, or help, or mentor women, and focusing on trying to improve the system as a whole. For example, creating inclusive classrooms, building inclusive work environments, addressing bias and harassment and creating equitable career paths and resources for all. Let's fix the system, not the women.

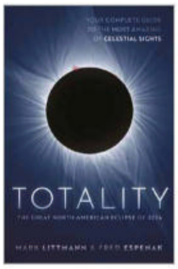
What advice would you give young women beginning a career in STEM?

It can get lonely as a woman in STEM, but it's not you, it's a faulty system, which you will need strength and skills to navigate. Find friends, allies and resources to do so, just like you do when you are solving a science problem. I'm often asked this question, but I wish I were asked about advice to give young men too. Nothing will really change unless they too are willing to change the culture, be allies and make space for others.

***Shohini Ghose** is a professor of physics and computer science at Wilfrid Laurier University in Ontario, Canada*

Totality: The Great North American Eclipse of 2024

Fred Espenak and Mark Littmann
Oxford University Press
£14.99 ● PB



Strange things happen when the Moon passes in front of the Sun. People who witness this phenomenon can become addicts, chasing solar eclipses all around the world. This book, written by two experienced observers, is a mini encyclopaedia of the solar eclipse. As well as summarising relevant mythology and modern science, it also acts as a practical guide to observing an eclipse.

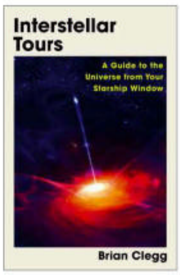
The very first chapter is a beautiful description of the experience, and subsequent chapters are interspersed with individual recollections of solar eclipses, making *Totality* something more personal than a standard guide to an astronomical phenomenon. It doesn't skimp on the science, offering an exceptionally clear explanation of why solar eclipses happen and how their timing occurs in the so-called 'saros' cycles, as first predicted by ancient Babylonians. Subsequent chapters delve into stone circles and the observations of the Mayan people, before discussing what we've learnt from eclipses about the structure of the Sun itself and how they provide an opportunity to test physics theories, such as general relativity.

There's a long description of the path of totality for the 8 April 2024 eclipse, though as that will be visible in the Americas this could be a little too detailed for the average UK reader. Included as well are maps for future eclipses, information that might be better sourced elsewhere. But all in all, this book successfully combines a wealth of information on varied aspects of solar eclipses and fosters a sense of anticipation for future ones. ★★★★☆

***Pippa Goldschmidt** is an astronomy and science writer*

Interstellar Tours

Brian Clegg
Icon Books
£18.99 ● HB



What would be it be like to sail between the stars? *Interstellar Tours* is a guide to a journey through the cosmos. Subtitled *A Guide to the Universe from Your Starship Window*, it is necessarily set a few hundred years in the future – but don't go expecting science fiction or idle speculation, or indeed pictures!

As the cruise ship *Endurance* speeds past now-centuries-old space probes, we discover that all the pictures are replaced with QR codes and links (so have your smartphone to hand). This feature was somewhat underused and, apart from a few videos, the 'viewing window' is more like a traditional slideshow, even including a few graphs and diagrams.

The concept of being on a physical tour becomes lost quite quickly. We jump from the Orion Nebula (1,500 lightyears distant) to exoplanets just a few dozen lightyears away from Earth, before heading back out 600 lightyears towards Orion to watch Betelgeuse go supernova. There then follows an assortment of waypoints including pulsars and black holes, mostly used as a prompt to talk about concepts such as gravitational waves or the history of pulsars, or theories of dark matter.

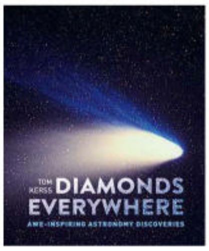
The writing itself is clear and the concepts well explained, generally suitable for someone with little or no astronomy background. The closest we get to really imagining what it would be like to gaze at celestial bodies is as we return home through the Solar System. While the book is interesting and well written, I missed the opportunity to imagine what it would really be like to go on an interstellar tour. ★★★☆☆

***Chris North** is Head of Public Engagement at Cardiff University School of Physics and Astronomy*

Diamonds Everywhere: Awe-Inspiring Astronomy Discoveries

ASTRO AWE

Tom Kerss
Collins
£16.99 ● HB



A book from Tom Kerss is sure to never disappoint. I flew through my first read of *Diamonds Everywhere*, but I imagine it will be a book I'll turn to again whenever I want to refresh my knowledge of our Solar System and beyond.

The subtitle of the book promises to reveal awe-inspiring astronomy discoveries and Kerss certainly knows how to stir the reader's imagination: daytime on Mars has a reddish-brown hue, but did you know that the Martian sunrise and sunset would be blue? And can you imagine what it might be like to be the first human to witness those brilliant azure shades? It's incredible to think that that person could be alive on Earth right now.

Given the choice, however, I think I'd like to experience the atmospheres of Uranus or Neptune, where diamonds can fall like sheets of rain (provided I had protection from the freezing conditions and other disagreeable aspects of Uranian or Neptunian life, of course).

Of the 101 topics covered – from the width of Saturn's rings to the strange and captivating activity of cryovolcanoes – there were only a handful that didn't immediately grab me. Still, even the slightly less sparkling topics covered throughout the book offer something new to be in awe of. Kerss's writing is engaging as always and his science rock-solid, accompanied by stunning images from telescopes around the world, including the Hubble and James Webb Space Telescopes, which are always especially breathtaking when seen in print. ★★★★☆

***Amy Arthur** is a science writer and author*

Ezzy Pearson rounds up the latest astronomical accessories

GEAR

1

2

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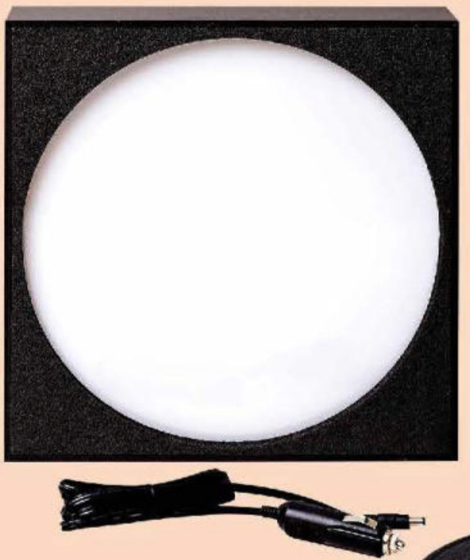


4

5

6

1 Nemo Stargaze reclining camp chair

Price £299.95 • **Supplier** Alpine Trek
www.alpinetrek.co.uk
Enjoy the starry sky in comfort wherever you are, with this reclining camping chair. It can be moved from upright to a reclined position by leaning back, with a padded headrest to ensure your comfort.

2 Baader C2 Swan-band filter

Price from £68 • **Supplier** The Widescreen Centre
www.widescreen-centre.co.uk
Designed for photographing comets, this filter transmits the 'Swan-band' C2 emission lines at 511nm and 514nm but not the OIII line, helping to increase contrast in the delicate details of a comet's tail. Can also be used to remove stars from your images.

3 Lacerta flatfield box for 10-inch Newtonian telescopes

Price £169 • **Supplier** 365 Astronomy
www.365astronomy.com
Flat fields can vastly improve the quality of your astro images and with this device uniformly illuminating your field of view, you'll be able to get consistent flat fields every time. Requires a 12V power supply and can be used with most telescopes, provided the panel covers the whole aperture.

4 Astro Essentials magnetic handle

Price £5 each • **Supplier** First Light Optics
www.firstlightoptics.com
These magnetic handles attach to the side of your Dobsonian, allowing you to manoeuvre the optical tube more easily. Though just 43mm in diameter, the magnet has a pulling force of up to 8kg and is covered in rubber to prevent it damaging your telescope.

5 Tilley black Tec-Wool hat

Price £90 • **Supplier** Ordnance Survey
shop.ordnancesurvey.co.uk
Keeping your head warm needn't mean sacrificing your personal style. This brimmed hat is made from Tec-Wool that will insulate or cool your head as needed, while the foldable flaps can be pulled down to protect your ears from chilly blasts.

6 Pegasus Ultimate Powerbox v3

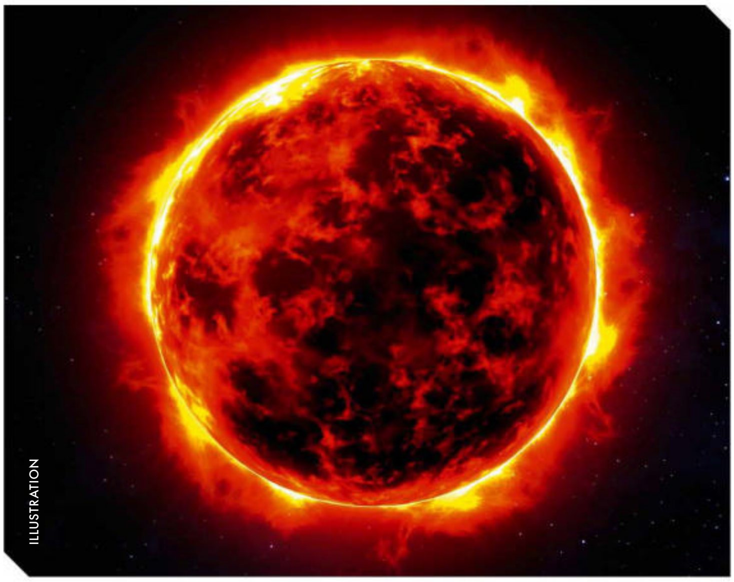
Price £540 • **Supplier** Rother Valley Optics
www.rothervalleyoptics.co.uk
Rather than juggling power packs and data cables, control all your hardware via this device, which comes with eight USB ports, eight 12V outlets, two adjustable outputs and three dew heater ports. Each USB port supports up to 2.5 amps.

Anita Chandran interviews Professor Katherine Freese

Q&A WITH A DARK STAR HUNTER

Researchers examining high-redshift objects in JWST data have detected for the first time what could be dark stars from the cosmic dawn

What is a dark star?
Dark stars are candidates for the first stars that formed in the Universe, around two hundred million years after the Big Bang. They would be made only of hydrogen and helium from the Big Bang, but unlike stars that are powered by nuclear fusion, would be powered by dark matter. Because there's no fusion happening inside them, they aren't very hot, and this means they can grow until they reach perhaps a million times the Sun's mass and a billion times its brightness. A single dark star from the early Universe could be as bright as an early galaxy containing many more standard stars.



▲ **Puffy, giant and (surprisingly) bright objects heated by dark matter, dark stars could be the earliest types of stars to form after the Big Bang**

How can a star be powered by dark matter?
The first stars formed in a very dark-matter-rich environment, at the centres of early proto-galaxies. Here, clouds of hydrogen were beginning to collapse down into fusion-powered stars but sitting in a big pool of dark matter.

We figured out that after a chain of reactions, the dark matter particles could annihilate each other and end up mostly as photons and other particles. These photons could get stuck in the collapsing gas cloud and dump all the energy previously contained in the dark matter into it.

This is a large enough source of energy to turn that collapsing cloud into a star. They're called dark stars because they're powered by dark matter, though they're not really dark at all. And in fact, their mass is only around 0.1 per cent dark matter.

How can a star be extremely bright but cool?
Brightness is related to a star's radius and temperature. While the temperature of a dark star is cool – around the same as the surface temperature of our Sun – its radius is enormous, so it becomes very bright. Because they are cool, it means there are not too many high-energy photons coming off their surface. If there were, then the star would stop growing and never reach the brightness of a galaxy.

Katherine Freese is the director of the Weinberg Institute for Theoretical Physics and Jeff & Gail Kodosky Endowed Chair of Physics at the University of Texas, Austin, specialising in theoretical cosmology and astroparticle physics

What can dark stars tell us about the Universe?
Dark stars live as long as they have dark matter fuel, and that could last millions to billions of years. But if the dark star moves away from a dark-matter-rich environment, it will start to collapse. As it collapses, it heats up. For smaller dark stars, you may get a hot core powered by fusion. But for big stars, around one million times as massive as the Sun, the collapse will form a black hole. We have found huge black holes in the early Universe, a billion times the Sun's mass, much earlier than they should have formed. If we had many black hole 'seeds' weighing one million times our Sun's mass, and they merged, then it could be possible to produce a supermassive black hole this early. This isn't possible with fusion-based stars.

How does one look for a dark star?
We are trying to differentiate between a dark star and an early galaxy in the James Webb Space Telescope (JWST) data. Early galaxies have the signatures of many different elements in their spectra, whereas dark stars should only be made of hydrogen and helium. When looked at by telescopes with the resolution that we have today, dark stars would also resemble single points. Early galaxies in principle could appear to have more of a size and shape.

What's next for your team?
In JWST's 2022 data, there were 700 probable early Universe objects, but only nine have measured spectra that allow us to be sure. Of these nine, only five have publicly available data. One of them is definitely an early galaxy containing signatures from many elements. There were three other objects whose spectra could be dark stars or early galaxies, but the data isn't good enough to differentiate them yet. What we're looking for down the line are early Universe objects magnified by 'gravitational lensing', where mass in front of a distant object bends the light around it, causing it to be magnified.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BRESSER Messier AR-152 OTAs - £753 Available in Longer Focus f/7.9 - 1200mm and Short Focus f/5 - 760mm versions
EXPLORE SCIENTIFIC BT-SF Giant Binoculars - starting at £1225
Deep Sky Astro Camera 26MP - £1499
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Check out the LUNT LS40 starter Hydrogen Alpha Solarscope - from £1036
Website: https://www.bresseruk.com/Astronomy/
Email: sales@bresseruk.com | For sales and advice call: 01342 837098
All prices correct at time of press. Subject to change. Errors and omissions excepted.

THE SOUTHERN HEMISPHERE

With Glenn Dawes

Don't miss big, bright Jupiter at opposition and enjoy a stroll around galaxy-packed Fornax

When to use this chart

1 Nov at 00:00 AEDT (13:00 UT)
15 Nov at 23:00 AEDT (12:00 UT)
30 Nov at 22:00 AEDT (11:00 UT)

The chart accurately matches the sky on the dates and times shown for Sydney, Australia. The sky is different at other times as the stars crossing it set four minutes earlier each night.

NOVEMBER HIGHLIGHTS

Jupiter is at opposition this month and at its brightest and largest for the year. Located in a rather barren region in Aries, this mag. –2.9 beacon can't be missed, with only Venus being more luminous. Although always visible through small scopes, don't miss appreciating it now when its size (about 50 arcseconds) is around 50 per cent larger than when close to conjunction, making it easier to see detail in its northern and southern equatorial belts and the Great Red Spot.

STARS AND CONSTELLATIONS

As we look below the plane of the Milky Way, with our Galaxy hugging the horizon, the constellation of Sculptor is nearly overhead, for it is home to the South Galactic Pole. The view looking *back* from this direction would show our Galaxy face-on. For example, we see the brilliant spiral NGC 253 nearly edge-on. From this galaxy, 11 million lightyears away, the Milky Way's nucleus, central bar and spiral arms would be magnificently displayed – sadly a view we can never share!

THE PLANETS

Towards the end of November, Mercury makes a poor return to the evening sky, remaining low in the western twilight. Saturn is still an early treat, being due north (culminating) around sunset, with Neptune following two hours later.

Being at opposition this month, both Jupiter and Uranus are rising in the twilight and visible all night. Jupiter leads its outer Solar System sibling by about an hour. Turning to the morning, Venus remains a fixed beacon rising around 03:00.

DEEP-SKY OBJECTS

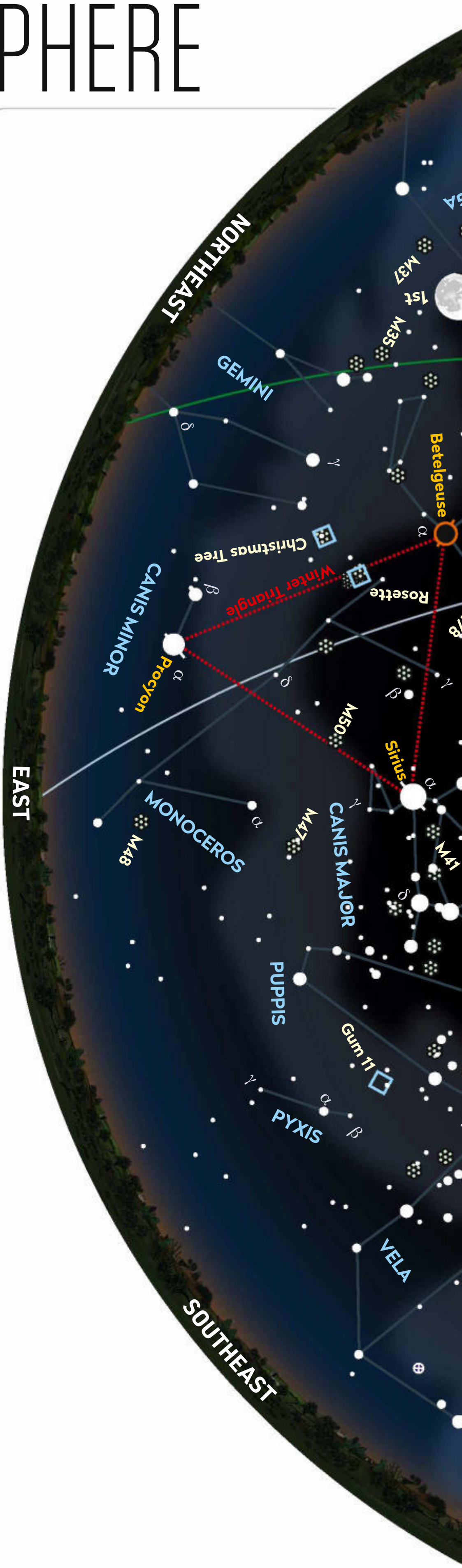
This month, a trip to two extragalactic denizens in Fornax, a constellation that's home to many galaxies, its brightest member being NGC 1316 (RA 3h 22.7m, dec. –37° 13'). In a 15cm telescope, this fine mag. +8.5 lenticular galaxy clearly shows a 2 x 3-arcminute hazy halo, rising to a brighter core region. Only 5 arcminutes north lies the galaxy NGC 1317, appearing as a bright, well-defined, 0.5-arcminute circular cloud.

Fornax also contains the brightest (mag. +9.5) barred spiral galaxy known: NGC 1365 (RA 3h 33.6m, dec. –36° 09'). Its bright, circular central core stands out, being embedded in a broad, 3-arcminute-long bar. This is surrounded by a faint halo that looks somewhat mottled, and on a good night with averted vision its spiral arms can be glimpsed, giving the galaxy the overall shape of a distorted letter 'S'.

Chart key

GALAXY
OPEN CLUSTER
GLOBULAR CLUSTER
PLANETARY NEBULA
DIFFUSE NEBULOSITY
DOUBLE STAR
VARIABLE STAR
COMET TRACK
ASTEROID TRACK
METEOR RADIANT
QUASAR
PLANET
STAR BRIGHTNESS:
MAG. 0 & BRIGHTER
MAG. +1
MAG. +2
MAG. +3
MAG. +4 & FAINTER

CHART: PETE LAWRENCE



NORTH
NORTHWEST
WEST
SOUTHWEST
SOUTH
Capella
PERSEUS
Almach
M34
M31
M110
M32
ANDROMEDA
Algol
NGC 1499
NGC 752
TRIANGULUM
M33
PEGASUS
Alpheratz
Elnath
27th
Pleiades
Hamal
ARIES
Great Square of Pegasus
Markab
Ecliptic
Uranus
Aldebaran
TAURUS
Hyades
Menkar
Jupiter
24th
PISCES
Alrescha
Circlet
Celestial Equator
Mirror of Venus
Mira
CETUS
Neptune
Steering Wheel
Enif
M15
EQUULEUS
ORION
M42
Rigel
ERIDANUS
NGC 253
Deneb Kaitos
21st
M2
AQUARIUS
LEPUS
South Galactic Pole
NGC 1317
NGC 1365
NGC 1316
FORNAX
NGC 300
SCULPTOR
NGC 55
Fomalhaut
NGC 7293
Saturn
NGC 7009
COLUMBA
CAELUM
HOROLOGIUM
NGC 1433
PISCIS AUSTRINUS
CAPRICORNUS
PHOENIX
DORADO
RETICULUM
Canopus
Achernar
GRUS
PICTOR
LMC
Tarantula Nebula
NGC 362
47 Tucanae
TUCANA
INDUS
18th
CARINA
VOLANS
MENSA
HYDRUS
SMC
South Celestial Pole
SAGITTARIUS
M55
CHAMAELEON
OCTANS
PAVO
NGC 6752
Eta Carina Nebula
Gem Cluster
Running Chicken
APUS
MUSCA
TRIANGULUM AUSTRALE
TELESCOPIUM
CORONA AUSTRALIS
Acrux
Coal Sack
Jewel Box
CRUX
Rigel Kent
CIRCINUS
ARA
CENTAURUS